Paraho

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PARAHO OIL SHALE DEMONSTRATION

RETORT OPERATIONS

FINAL REPORT
VOLUME 3

Paraho

PARAHO FINAL REPORT

RETORT OPERATIONS

VOLUME 3

AUGUST 31, 1976

PREPARED

BY

DEVELOPMENT ENGINEERING, INC.

for

PARAHO DEVELOPMENT CORPORATION
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FOREWORD

Under a lease approved by the President of the United States in May, 1972, Paraho undertook, in cooperation with the federal government, to demonstrate the engineering, economic and environmental feasibility and desirability of the Paraho processes and hardware for retorting oil shale. This Final Report to participants of the Paraho Oil Shale Demonstration is a six-volume document that describes the research and development operations, the engineering design and cost estimating, and the commercial evaluation studies carried out from late-1973 to mid-1976.

THIS VOLUME 3 IS CONSIDERED CONFIDENTIAL UNDER THE TERMS OF THE PARTICIPANTS AGREEMENTS WITH PARAHO CORPORATION AND DEVELOPMENT ENGINEERING, INC. MORE-OVER, BECAUSE OF THE COMMITMENT TO THE GOVERNMENT NOT TO PUBLISH INFORMATION PREMATURELY, DISTRIBUTION SHOULD BE STRICTLY CONTROLLED ON A NEED-TO-KNOW BASIS UNTIL AFTER THIS MATERIAL HAS BEEN PUBLISHED BY THE GOVERNMENT OR PARAHO.

The field operations were conducted at the Anvil Points Oil Shale Research Facilities located on the Naval Oil Shale Reserves near Rifle, Colorado. Administration of these leased facilities was transferred from the Bureau of Mines (BOM) to the Energy Research and Development Administration (ERDA) when the latter agency was formed in 1974.

The Paraho Oil Shale Demonstration was privately sponsored by the following seventeen participants at a total cost of $9.4 million:

Sohio Petroleum Company
Southern California Edison Company
The Cleveland-Cliffs Iron Company
Gulf Oil Corporation

Arthur G. McKee and Company
Kerr-McGee Corporation
Shell Development Corporation
Standard Oil Company (Indiana)
The Carter Oil Company (Exxon)
Mobil Research and Development Corporation
Webb-Gary-Chambers-McLoraine (Group)
Sun Oil Company
Texaco Inc.
Phillips Petroleum Company
Atlantic Richfield Company
Marathon Oil Company
Chevron Research Company

These participants received the right to license Paraho's oil shale technology on favorable terms for their support and cooperation which are gratefully acknowledged.

The results of Paraho's operations at Anvil Points are encouraging. They demonstrate that the process works, that the equipment is operable and durable, that thermal efficiencies and yields are high, and that the entire system developed is environmentally acceptable. The extended periods of Paraho retort operations and the results obtained demonstrate this. The evidence includes the 77-day Pilot Plant run and the 56-day Semi-Works run, both of which were terminated voluntarily.

After the 56-day retort run, 10,000 barrels of Paraho crude shale oil were shipped to the nearby Gary Western Refinery and converted into military products. This federally funded work was done for the U.S. Navy's Energy and Natural Resources Research and Development Office. That Office coordinated the refining and the nationwide, refined product testing program and publishing a report entitled:

Production and Refining of 10,000 Bbl. Paraho Crude Shale Oil Into Military Fuels, U. S. Navy Contract #N0014-75-C-0055

A retorted shale management research project jointly funded by the Bureau of Mines and Paraho will be completed in late-1976 at an estimated additional cost of $0.5 million. At that time, a report entitled, "Retorted Shale Management", will be issued as the concluding volume of this report.

RETORT OPERATIONS

Final Report

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1 INTRODUCTION

The Paraho Oil Shale Demonstration Project was a program to prove the Paraho Process and Hardware for retorting oil shale.

The term "oil shale" is commonly used to cover a wide range of materials of laminated, solidified sediments, and organic material called kerogen. This is a high molecular weight component of indefinite composition. It is insoluble in common solvents, but undergoes a destructive distillation or pyrolysis at temperatures above 600°F. This results in an "oil" and some gas. The thermal decomposition of oil shale has so far proved to be the only practical method of obtaining the oil from oil shale.

Shale oil has been produced from oil shales in a number of foreign countries for several centuries. This production has been on a small scale. Small scale production has also occurred in the United States. Discovery of petroleum ended the United States shale oil industry in the middle 1850's.

Paraho Corporation and Development Engineering, Inc. developed a vertical kiln technology and the hardware for thermal reactions. The companies used the technology and equipment in the limestone industry. Three large capacity Paraho kilns have been operating commercially for several years. Limestone is a geological kin of oil shale marlstone, and a number of analogies may be drawn.

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This report covers the retort operations of the Paraho Oil Shale Demonstration Program. The project included a 4 1/2 foot O.D. Pilot Plant retort and 10 1/2 foot O.D. Semi-Works unit. Two operating modes were studied, namely a Direct Heated Mode and an Indirect Heated Mode.

The results of the Demonstration Program show that the Paraho process works, that the equipment is durable, and the overall recovery of hydrocarbon material in the forms of oil and gas is very high. The entire operation is environmentally acceptable.

1.1 OBJECTIVES OF THE PROGRAM

The principal objectives of the program were:

- o Demonstrate the operability of the Paraho retorts for processing oil shale.
- o Confirm that improved temperature and gas and shale flow controls will give oil recoveries:

  Direct Heated Retort - 90%

  Indirect Heated Retort - 100%

- o Minimize the formation of clinkers.
- o Determine scale factors between 30 inch Pilot retort and 8 1/2 foot Semi-works retort.
- o Test performance of retorts on 25-35 gallon per ton shales

- Demonstrate the engineering and environmental feasibility of the Paraho technology.

- Determine compaction characteristics of Paraho retorted shale.

- Develop design basis for a commercial evaluation.

1.2 ACCOMPLISHMENTS OF THE PROJECT

The operations of both the Pilot Plant and the Semi-Works Retorts demonstrate that the process works efficiently, that the equipment is durable, and acceptable environmentally.

Extended operation periods of a 77-day Pilot Plant run and a 56-day Semi-Works run evidence the operability of the process and the hardware. Because of the Projects' research nature, both extended runs were voluntarily terminated. Inspection of the equipment and the operation stability, indicate that the runs could have been extended indeterminately.

Both retorts demonstrated good operability. When electric power outages occurred or auxiliary equipment malfunctioned, the retorts could be placed on standby and left full of hot shale. When ready to resume operations, the equipment would be restarted and operations continued without having to empty, refill, and restart the retort. Runs given in Table No. 1-1 are noteworthy since extended operations with high on-stream factors were demonstrated. On-stream factors of less than 100% indicates the retort was placed on standby for correction of malfunctions and operations were continued.

Table 1-1

RETORT OPERABILITY

RETORT	RUN NO.	PROCESS	RUN LENGTH (DAYS)	% ON-STREAM TIME
PILOT PLANT	16	DIRECT HEATED	77.0	99.1
PILOT PLANT	18	DIRECT HEATED	27.3	94.6
PILOT PLANT	19	DIRECT HEATED	12.1	99.8
SEMI-WORKS	7	DIRECT HEATED	56.0	88.4
SEMI-WORKS	20	DIRECT HEATED	25.6	99.7
SEMI-WORKS	23	INDIRECT HEATED	31.2	99.6
SEMI-WORKS	28	INDIRECT HEATED	10.6	100.0

The Paraho kiln over all produced up to 92 - 96 Vol.% Fischer assay recovery of the liquid shale oil, and in addition from 8-12 of the kerogen heating value in a product gas.

The Direct Heated Mode proved a liquid oil recovery of 92 Vol.% F.A. and 96 Vol.% when the C_5+ oil is removed from the gas plus 7200 SCF/Ton of low Btu gas. The Indirect Heated Mode, when using an outside source for heater fuel, produced a liquid oil yield of 92 Vol% F.A. and 95 Vol% C_5+ with 500 SCF/Ton of high Btu gas.

The Direct Heated Mode has demonstrated the burning of retorted shale's residual carbon as a source of fuel. The Indirect Heated Mode heat requirement has been demonstrated at 380,000 Btu

per ton.

In the Direct Heated Mode, the Semi-Works unit completed a 25-day confirmation run, including operation with variable studies. The pentane and heavier oil produced during this run averaged 96 Vol% of Fischer Assay oil yield.

In the Indirect Heated Mode, the Semi-Works was operated for a number of exploratory and variable investigation runs. A 30-day operability run was completed, and some variable studies conducted during this run. A 12-day confirmation run was conducted with the best operating conditions producing a liquid oil yield of 95 Vol% when the C_5+ oil is removed from the gas. This yield is before making fuel deductions for the external heater.

Variable studies with high mass rates were conducted in both the Pilot Plant and the Semi-Works. Based on pounds of shale processed per hour per square foot, the Pilot Plant was tested above 700 and the Semi-Works retort tested above 600 in the Direct Heated Mode. A wide range of process variables was studied including shale grade. Neither retort was tested to the limits of the process variables. Auxiliary equipment limitations also prevented extending process variations beyond the tested ranges.

The shale temperatures in both retorts in the Direct Heated Mode were controllable in low ranges to minimize carbonate decomposition and maximize oil recovery and eliminated clinker formation. Both retorts were operated to accommodate fluctuations in shale size, shale grade, and processing over a wide range of conditions. No major differences were shown between the Pilot Plant and Semi-Works

retorts under the same operating conditions including yields and product properties.

Both retorts were capable of long standby periods, permitting repairs to auxiliaries or for power outages, with continued operation upon resumption of process flows.

Operations of the Paraho retort shows that oil mist formation can be controlled by a change of process variables.

Paraho retorted shale does not require the use of water to control dusting after being placed in canyons near the retort.

2 SUMMARY

The Paraho retort contains a number of patented features for accurately controlling the flow of solids and gases. The retort is relatively simple, with only two moving parts. It utilizes counter-current flow and a gravity transport of shale through the retort vessel. The process gas may be introduced into three different levels in the shale bed. The Paraho process involves the accurate control of the mixtures of the process gases as well as their bed locations to control bed temperatures. The Paraho patented processes include the Direct Heated Mode and the Indirect Heated Mode.

2.1 BACKGROUND

When heated, the kerogen in oil shale forms hydrocarbon vapors, fixed gases, and carbon which remains in the retorted shale particles. The function of the retort is to economically recover these energy values from the oil shale.

The oil shales of Colorado, Utah and Wyoming are marlstones containing large quantities of dolomite, a mixture of magnesium and calcium carbonates. These carbonates decompose at elevated temperatures to form metal oxides and carbon dioxide. The endothermic decomposition rate is rapid for magnesium carbonate at temperatures above 1000^{o}F and for calcium carbonate above 1500^{o}F. When the temperature in a retort containing oil shale is elevated, it will first stabilize at the magnesium carbonate decomposition temperature. When additional heat is available after decomposition of the

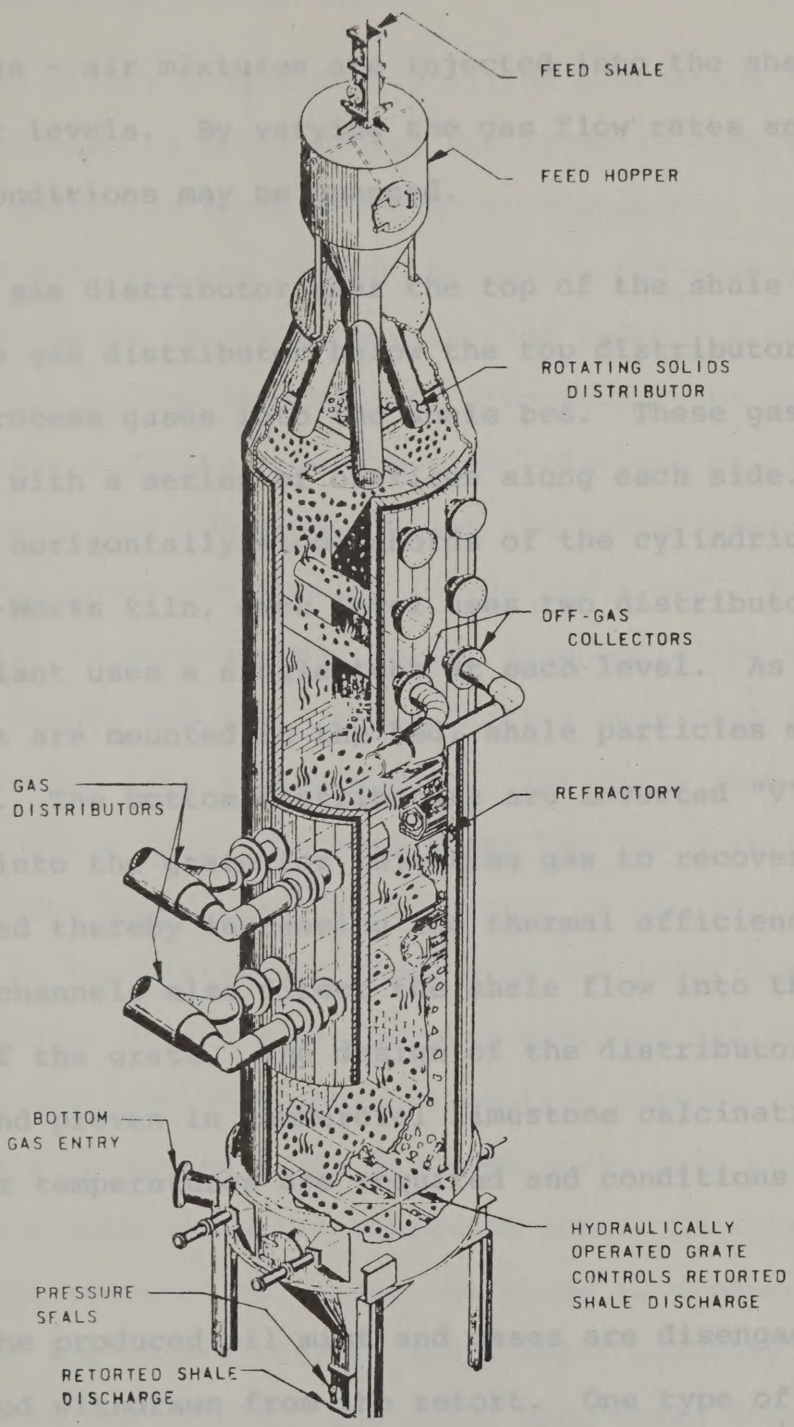
magnesium carbonate, the temperature will rise and stabilize at the calcium carbonate decomposition temperature. After decomposition of all the carbonates, additional heat will raise the temperature and shale particles tend to fuse together.

In oil shale retorting, the endothermic carbonate decomposition wastes heat and the produced carbon dioxide decreases the heating value of the product gases. Low shale retorting temperatures will minimize the carbonate decomposition and maximize the recovery of oil and gas from the kerogen in the oil shale at very high thermal efficiency, and eliminates clinker formation.

2.2 THE RETORT

The Paraho retort is a stationary, vertical, cylindrical, refractory lined kiln, equipped with shale and gas handling devices. The retort contains a number of patented features for control of the process materials streams. The retort with only two moving parts, the grate mechanism and the raw shale feeder, is shown in Figure 2-1. The unit processes lump size solid material.

The crushed and sized fresh shale is fed into the top hopper through a seal. The shale particles are placed in the retort by a rotary distributor, uniformly across the surface of the shale bed without substantial segregation. The shale continuously flows downwardly, by gravity, as a moving bed. A patented grate mechanism, coordinated with the feed mechanism, removes retorted shale, while maintaining a constant



Paraho RETORT

FIGURE 2-1

depth of bed. The discharged, retorted shale passes into a conical hopper and exits the kiln environment through a seal.

Gas - air mixtures are injected into the shale bed at different levels. By varying the gas flow rates and mixtures, retorting conditions may be changed.

A gas distributor near the top of the shale bed and an intermediate gas distributor below the top distributor are used to inject process gases into the shale bed. These gas distributors are tubular with a series of orifices along each side. The tubes are mounted horizontally along chords of the cylindrical retort. In the Semi-Works kiln, each level uses two distributors, while the Pilot Plant uses a single tube at each level. As the distributors are mounted in the bed, shale particles must flow around them. The bottom distributors are inverted "V" shaped channels built into the grate for injecting gas to recover heat from the shale bed thereby increasing the thermal efficiency of the process. The channels also direct the shale flow into the moving mechanism of the grate. The design of the distributor was developed and proven in commercial limestone calcination operations, where higher temperatures are required and conditions are more severe.

The produced oil mist and gases are disengaged from the shale and withdrawn from the retort. One type of off-gas collector used is embedded in shale near the top of the bed. Incoming shale must pass over these off-gas collectors. Another type uses peripheral ports in the top cone of the retort above the surface of the shale bed. A major factor in the high retort

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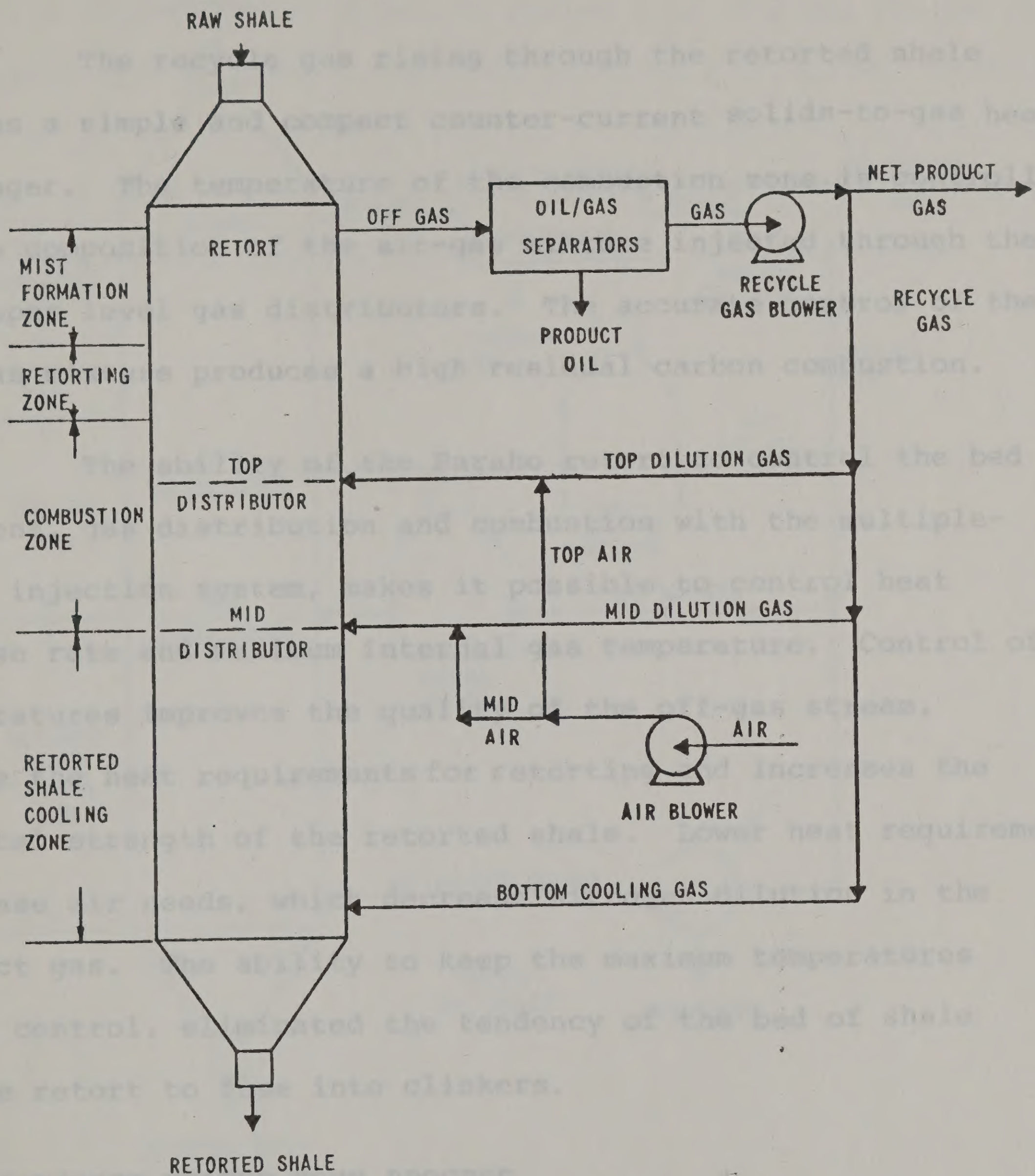
thermal efficiency is the low off-gas temperature.

2.3 DIRECT HEATED MODE PROCESS

The Direct Heated Mode utilizes combustion in the shale bed produced by distributing air directly into the bed as the crushed and sized fresh shale moves downwardly, Figure 2-2. The shale is fed into the top of the retort and removed at the bottom so as to retain a constant bed depth. A top distributor set and an intermediate distributor set inject process gas-air mixtures into the upper portions of the shale bed. By controlling the quantity and the composition of these gases, several zones are created in the shale bed. The upper zone is a mist formation zone, which, also cools the produced hydrocarbon vapors and gas. It is in this zone that the oil vapors are formed into a stable mist. The shale then proceeds into the retorting zone, the area above the top distributor set. In the retorting zone, the organic matter in the shale is decomposed by the heat in the rising hot gases from the lower combustion zone. The decomposition of oil shale kerogen produces oil vapors and gas. A carbon residue from this thermal reaction remains in the retorted shale particles. The retorted shale then proceeds to the combustion zone below the retorting zone. In this combustion zone, the heat required to retort the shale is produced by combustion of the carbon residue and a small quantity of recycle gas returned to the retort. The shale then moves downwardly from this hot zone to a cooling zone below the intermediate distributor set. In the cooling zone, the heat from the retorted shale is transferred to rising stream of cool recycle gas introduced



PARAHO DIRECT MODE PROCESS
FLOW DIAGRAM

FIGURE 2-2

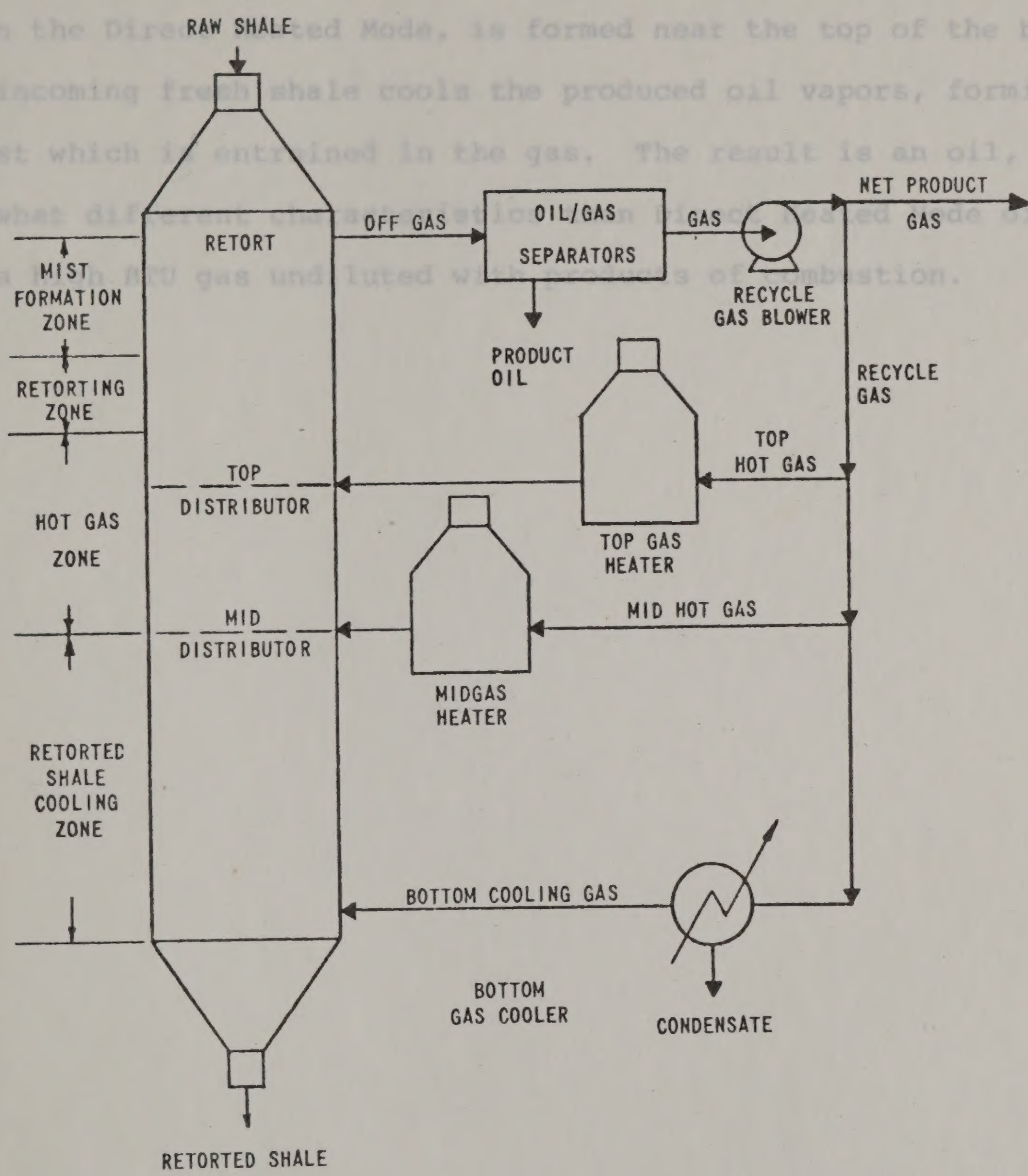
into the bottom of the shale bed through distributors above the grate.

The recycle gas rising through the retorted shale acts as a simple and compact counter-current solids-to-gas heat exchanger. The temperature of the combustion zone is controlled by the composition of the air-gas mixture injected through the two upper level gas distributors. The accurate control of the air-gas mixture produces a high residual carbon combustion.

The ability of the Paraho retort to control the bed movement, gas distribution and combustion with the multiple-level injection system, makes it possible to control heat release rate and maximum internal gas temperature. Control of gas temperatures improves the quality of the off-gas stream, lowers the heat requirements for retorting and increases the physical strength of the retorted shale. Lower heat requirements decrease air needs, which decrease nitrogen dilution in the product gas. The ability to keep the maximum temperatures under control, eliminated the tendency of the bed of shale in the retort to fuse into clinkers.

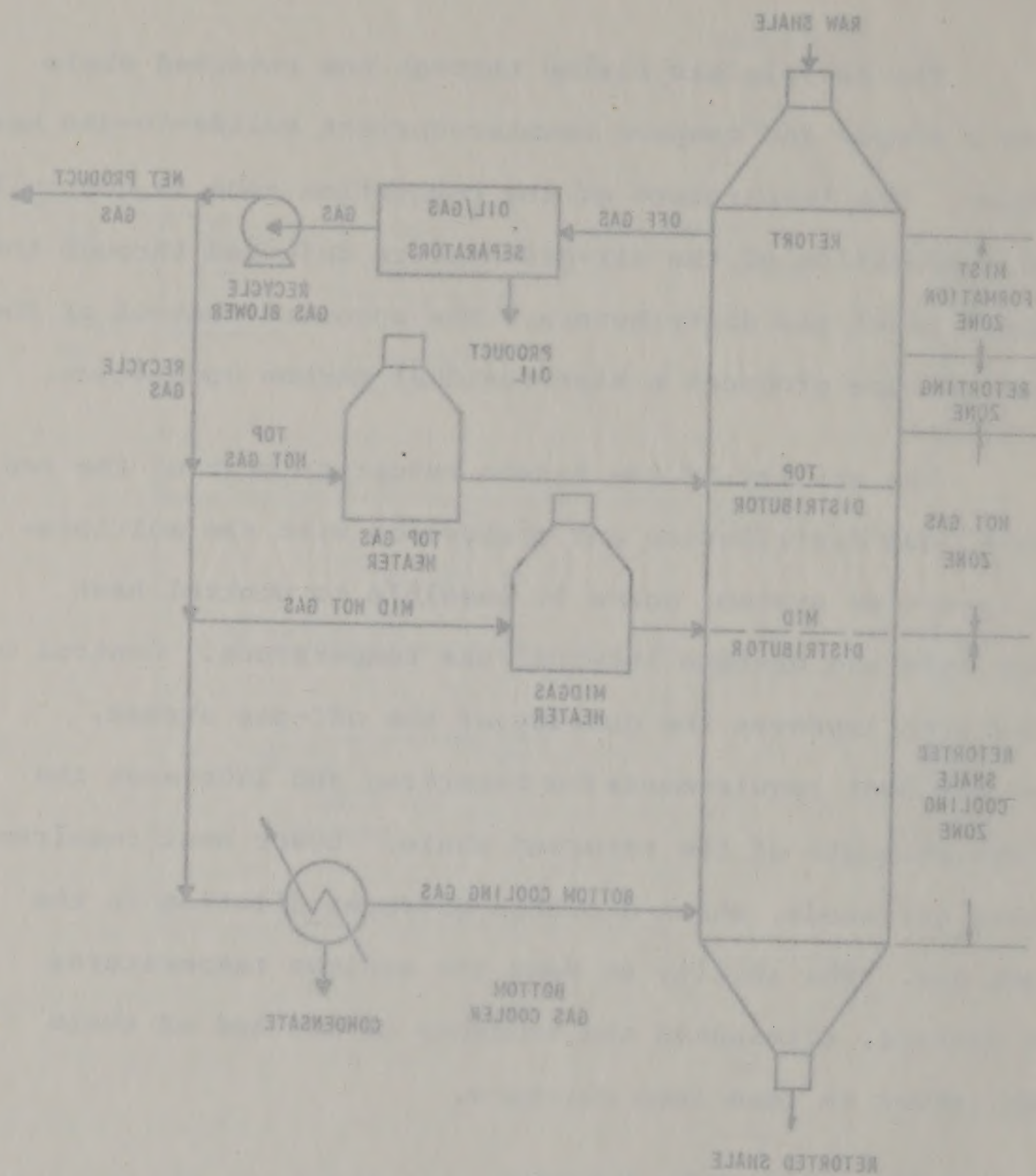
2.4 INDIRECT HEATED MODE PROCESS

In the Indirect Heated Mode, Figure 2-3, recycle gases are heated in external heaters. These heated gases are then injected into the shale bed through one or both of the upper levels of gas distributors. Cool recycle gas is added through the grate distributor to cool the retorted shale. The rising recycle gas is heated by the retorted shale and when mixed with



PARAHO INDIRECT HEATED MODE PROCESS
FLOW DIAGRAM

FIGURE 2-3



PARAHO INDIRECT HEATED MODE PROCESS
FLOW DIAGRAM
FIGURE 2-3

the externally heated recycle gas, sufficieny heat is provided for retorting the shale above the top distributor. Oil mist, as in the Direct Heated Mode, is formed near the top of the bed. The incoming fresh shale cools the produced oil vapors, forming a mist which is entrained in the gas. The result is an oil, of somewhat different characteristics than Direct Heated Mode oil, and a high BTU gas undiluted with products of combustion.

3. DIRECT MODE

3 DIRECT HEATED MODE OPERATION

3.1 INTRODUCTION

The Direct Heated Mode process, Appendix F, drawing 4, utilized combustion in the shale bed to supply the heat necessary for retorting. The products of this mode of retorting are mixed gases, oil and coke or carbon. The carbon is dispersed within the shale particles, and in this mode of retorting, it is burned in the retort as the principal source of heat for the process.

Air for the combustion diluted with recycle gas is introduced through the two upper distributors. Only sufficient combustion air is injected into the bed to maintain the desired temperature profile while burning the carbon needed to supply the process heat. Recycle gas flows and products of combustion are controlled to provide enough hot gases to retort the shale in the retort zone above the top distributors and above the combustion zone.

3.2 RETORT CONTROL

The Pilot and Semi-Works retorts have proven to be controllable and operable in the Direct Heated Mode of retorting. A prime requirement for good operation of this mode of retorting is a good startup procedure. The procedure must establish the desired temperature profiles and heat inventory in all parts of the retort. This heat or thermal inventory must be developed in a controlled manner so the oil vapors will form

mist in the gas stream and not condense on the shale particles. Such a startup procedure was developed and is described in Section 6.

In the Direct Heated Mode, temperature and gas analysis measurements were used as a guide to retort operational adjustments. The retort temperatures above the top distributor had to be high enough to maintain combustion. When the temperatures at this point are too low, oxygen will pass through the combustion zone and enter the retorting zone where it would consume oil values. If temperatures were lowered further, combustion above the top distributor would stop and oxygen would appear in the recycle gas. Successful re-establishment of combustion at the top distributor has been attained by slowing the shale rate.

The temperature of the combustion zones were also controlled by adjusting the ratio of air and gas flowing to the distributors for a given air rate per ton of oil shale. To monitor the temperatures in the retorts, temperature sensing probes were installed. Combustion reactions were also monitored by measuring the CO_2, CO, and O_2 in the product gas. A rapid decrease in CO_2 indicates that combustion of oil had started supplying part of the heat needs.

Early retort operations showed the most effective method of retort control for a given set of experiments was to maintain constant air and gas flows with the analog flow controls. The raw shale feed was set at a predetermined rate

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with adjustments made to the rate if the measured retort temperatures and product gas analysis were outside a designated range. Varying the shale rate effectively changed the air and gas rates per ton of raw shale, which in turn changes the retort temperatures and the quantity of carbon dioxide produced by carbonate decomposition.

3.3 PILOT PLANT OPERABILITY

The Pilot Plant proved to be operable beginning with the first startup. Continued improvement in the raw shale storage and handling facilities in control techniques resulted in an excellent record of operability (see the Pilot Plant Operating Summary in the Appendix Section A). Although operable, wide fluctuations in the pressure drop across the retort was experienced in the early runs. Investigations showed the equilibrium was changing due to changes in the size of the shale being fed to the retort. These changes in shale size were a result of an accumulation of size segregation problems throughout the shale storage and handling system. Changes in operating procedures and a re-design of the surge bins and hoppers reduced the segregation and an equilibrium operation could be maintained.

The retort operations were stable over a wide range of operating variables, feed characteristics, and ambient conditions. A minimum of control correction was found to be necessary to adjust for variations in shale size, shale gradation, shale fines, and moisture content of the raw shale feed. When

major variations in the feed material caused upsets, operational recoveries were generally possible permitting retort operations to be continued. When auxiliary equipment malfunction occurred, the retort could be put on standby until it was corrected and the operation would be resumed. A standby was accomplished by stopping all gas and shale flows and allowing the retort to sit full of hot shale. When ready to resume operation all of the equipment is restarted and flows reset and it was not necessary to empty or refire the retort. Recovery from standby outages for major repair to equipment on the retort or auxliaries was achieved for standby periods of as long as 18 hours. Standbys for short outages did not affect the equilibrium conditions.

Operational stability was maintained for long periods of time and required only a minimum of operator attention. The Pilot Retort was operated in the Direct Heated Mode to supply an emergency source of purge gas for the Semi-Works Retort when the latter was operated in the Indirect Heated Mode. The Pilot Retort gave excellent operational performance and only required about 15 minutes of the operator's attention during each 8-hour shift. There was one Pilot Plant retort run of 77-days that had an on-stream factor of 99%. The retort was on standby for 1% of the time to repair control valves, blowers, and calibrate conveyor scales. The run was terminated voluntarily due to a planned turnaround on the Semi-Works retort. Pilot Plant inspection showed the retort could have operated for a much longer period. The on-stream factor for a four month period was 95%.

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3.4 PILOT PLANT VARIABLE STUDIES

The variables of air and gas flow rates, shale mass rates, and shale size and quality were explored in the Pilot Plant operations. A broad range of operable conditions was achieved with minor effects on yields and product quality. A listing of all test data is given in the Appendix Section D-1. The Table 3-1 illustrates the range of variables studied during this program:

TABLE 3-1

Item	Max	Min
Total Air Input SCF/T	7330	4240
Air of Total to Top Dist. %	100	46
Air of Total to Mid Dist. %	54	0
Gas at Top Dist. %	50	22
Gas at Mid Dist. %	100	48
Bottom Air SCF/T	400	0
Bottom Recycle SCF/T	15010	6620
Total Recycle Gas SCF/T	18520	12810
Mass Rate $lbs/hr/ft^2$	720	170
Shale Top Size In.	2	1 3/4
Shale Bottom Size In.	7/8	3/8
Shale Quality GPT	32	18

The effects of shale size and grade were not significant, within the range examined, on the dependent variables of oil yield, gas yield, and product qualities. There was a maximum shale size limitation of two inches. The retort internal clearance did not allow the free flow of

shale particles larger than 2-inch, therefore only ranges of particles up to a 2-inch top size were investigated.

No tests were made to determine the effect of shale particle size distribution or shape factor on the retort operation as the equipment in the crushing and storage plant was not capable of producing the retort feed necessary for this type of variable studies.

The mine was not geared or equipped to selectively mine the thin, rich or lean strati. Therefore, shale grade could not be varied in a planned experiment. However, there was wide variation in grade as shown with no significant change in percent Fischer Assay oil yield.

The division of air between the top and middle distributors was set at approximately 2/3 of the total air input to the top for a major portion of the test program. Good operability was established early in the program under these conditions and the vertical distribution was maintained to examine the effect of other process variables. Pilot Plant Run PP-19 explored a broad range of air distribution between the top and middle gas distributors. There were indications of higher product oil fluidity with higher percentage of total air going to the middle distributor.

Changes in percentage recycle gas in the air-gas mixture used at the top and mid distributors affected location, depth of zone, and temperature on the combustion zones as shown by the bed temperature measurements. By decreasing the recycle

gas, a higher temperature and shorter combustion zone resulted. For this reason, a low recycle gas ratio was preferred at the top distributor, holding combustion close to the distributor. Therefore, gas mixture adjustments did not have to be made for different process conditions to maintain a desired temperature profile in the retort, for example test PP-16 B-3 and C-1, Appendix D-2.

Recycle gas for the mid distributor was held high, usually about 50% of the total mixture, to lower the combustion intensity in this area and to decrease the amount of recycle gas burned to obtain preferential carbon combustion and increase the depth of combustion above the mid distributor.

Bottom recycle rates were generally set to provide adequate retorted shale cooling in the range of 300°F to 450°F. By increasing the bottom recycle rates, a greater heat recovery is obtained from the retorted shale, thus allowing an equivalent reduction in air requirements. However excessive bottom recycle gas rates can affect the heat transfer rates in the shale preheat zone near the top of the retort which gives poor oil mist formation characteristics. A broad range of operable recycle gas rates was explored in the Direct Heated Mode.

High mass rates were considered to be a major item of economic importance. For this reason, many of the early variable studies were directed toward this goal. Good operations were achieved at mass rates of up to 650 $lbs/hr/ft^2$. This throughput was calculated on the weight of dry raw shale per hour

per square foot of bed cross section in the unrestricted section of the retort (4.909 ft^2 for the Pilot Plant). A short period of operation was achieved at 720 $lbs/hr/ft^2$ but problems occurred with auxiliaries, and the test was not repeated. Adjustment of gas and air orifice meters, bed heights, and distributor gas entry velocities would be necessary before problems associated with high mass rates could be clearly defined.

A representative series of Pilot Plant stable operations representing a moderate range of variables is presented in Tables 3-2 and 3-3. Some individual test periods have been combined where operating conditions are comparable. Table 3-2 is a brief summary of the operating conditions and yields. Table 3-3 shows the product properties of these tests and the relationship of total air input to product gas quantity and quality is indicated. The total product gas quantity is a function of air input because the diluent gases present (mainly nitrogen) are proportional to air input. Also, with a greater air input more carbonates are decomposed producing more CO_2. Retorted shale properties change with the relative air rates (SCF/T) being used. When the SCF/T of air is increased, combustion temperatures are raised, more residual carbon is burned, and more carbonates are decomposed. These changes in retorted shale properties can be seen in the test data from Pilot Plant Direct Heated Mode operations, Appendix Table D-2, Run PP-16, Test A-9 vs. Run PP-19, Test D.

Oil properties show higher API gravity and lower

TABLE 3-2

PILOT PLANT - DIRECT HEATED MODE OPERATING CONDITIONS AND YIELDS

			OPERATING CONDITIONS					PRODUCT YIELDS	
				Air Input					
Run No.	Test No.	Combined Test Length, Hrs.	Mass Rate Lbs/Hr/Ft^2	Total SCF/T	% To Top Dist.	Top & Mid Gas, SCF/T	Bottom Gas, SCF/T	Oil Collected Wt% F.A.	Gas (Wet) SCF/T
PP-5	A	16	181	6,730	100	3,900	13,450	89	10,900
PP-5	D, E	32	380	4,330	76	2,980	10,110	91	5,770
PP-9	B	10	633	4,580	68	2,660	12,590	92	5,350
PP-10	B,C,D-2	40	614	4,750	70	2,570	12,820	91	5,250
PP-16	A-3 - A-7	120	399	5,390	81	3,030	13,920	92	8,080
PP-19	J	24	425	5,170	56	2,110	13,600	90	7,740

TABLE 3-3

PILOT PLANT - DIRECT HEATED MODE PRODUCT PROPERTIES

Run No.	Test No.	Combined Test Length, Hrs.	Total Air Input, SCF/T	PRODUCT OIL PROPERTIES			PRODUCT GAS PROPERTIES (Dry)		
				Gravity °API	Visc. SUS @130°F	Ramsbottom Carbon Wt%	N_2 Vol%	CO_2 Vol%	Gross Heating Va. BTU/SCF
PP-5	A	16	6,730	19.6	145	N.A.	62.6	28.6	83
PP-5	D, E	32	4,330	21.6	88	1.60	62.6	28.6	117
PP-9	B	10	4,580	21.1	93	1.34	65.1	23.5	116
PP-10	B,C,D-2	40	4,750	21.2	96	1.67	65.3	22.5	121
PP-16	A-3 - A-7	120	5,390	20.4	108	1.65	62.7	29.4	77
PP-19	J	24	5,170	20.2	112	2.24	59.3	25.0	124

Ramsbottom carbon content with the lower air input. Oil yield shows little variation with these changes.

The complete test data for the Direct Heated Mode Operations in the Pilot Plant is shown in Appendix Section D-2.

3.5 SEMI-WORKS OPERABILITY

The demonstration of operability in the Semi-Works retort began with Run SW-7. This operation covered 56 days and achieved an operating factor of 88.4%. A complete summary of all retort operations is given in Appendix Section D-2.

A 26 day conformation demonstration run for the Direct Heated Mode was made after correcting the mechanical and operating problems that were apparent earlier in the program, see Table 3-4. This run, SW-20, shows a 99.7% operating factor and provides the design basis for commercial evaluation. Five power outages accounted for 50% of the total time lost. An additional standby period was necessary for the repair of a retorted shale conveyor belt.

Only a momentary effect of these standbys could be seen in the temperatures,products, or other data, amply demonstrating the stability of the process.

During previous operations, standby periods of up to 21 hours have been sustained in the Semi-Works retort. Operation was continued by restarting the equipment and resetting all flows, without refiring.

Ramsbottom carbon content with the lower air input. Oil yield shows little variation with these changes.

The complete test data for the Direct Heated Mode Operations in the Pilot Plant is shown in Appendix Section D-2.

3.5 SEMI-WORKS OPERABILITY

The demonstration of operability in the Semi-Works retort began with Run SW-7. This operation covered 56 days and achieved an operating factor of 98.4%. A complete summary of all retort operations is given in Appendix Section D-2.

A 26 day conformation demonstration run for the Direct Heated Mode was made after correcting the mechanical and operating problems that were apparent earlier in the program, see Table 3-4. This run, SW-20, shows a 99.7% operating factor and provides the design basis for commercial evaluation. Five power outages accounted for 50% of the total time lost. An additional standby period was necessary for the repair of a retorted shale conveyor belt.

Only a momentary effect of these standbys could be seen in the temperatures, products, or other data, amply demonstrating the stability of the process.

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MAJOR EQUIPMENT REVISIONS TO THE SEMI-WORKS PLANT

TABLE 3-4

1. Raw and Retorted weigh belt systems were revised to provide greater weighing accuracy and reliability.

2. Gas sampling and analysis was revised including continuous O_2 analysis and on-line gas chromatograph.

3. Replaced and repositioned temperature-pressure probe.

4. Installed a raw shale polishing screen to reduce fines in retort feed.

5. Installed a coalescer and revised the oil handling system to increase the oil recovery efficiency.

6. Installed condensate drains on all recycle gas lines.

7. Double bottom rotary seals of a revised design were installed to reduce gas leakage.

8. Revisions were made to the raw shale rotary distributor for improved shale feed.

9. Revised the hydraulic system to improve control of the discharge grate.

The off-gas collector systems for the Pilot Plant and Semi-Works retorts are shown in Drawings 8 and 9 in Appendix F. Gases leave the shale bed at a much higher velocity in the Semi-Works retort because of the greater reduction in flow area entering the collector. This change in flow pattern and velocity contributed to a greater amount of sediment carry-over from the Semi-Works retort as shown by oil analysis from Test Data in Appendix D-2 and D-3.

A specific evaluation of the off-gas collection technique was made during Runs SW-12 through 16 by the removal of the submerged off-gas collectors. Other process and equipment changes completed at the same time, made an evaluation of this change difficult. These runs were not successful in sustaining a good operation and a return to the submerged collectors and lower distributor orifice velocity changes were made. The runs testing the elimination of collectors were hampered by several mechanical and operational problems that may have been responsible for the difficulties encountered.

The process function of the air-gas distributor system used for the Semi-Works retort is the same in the Pilot Plant. The principles of air-gas mixtures and the effect of this variable were identical in both retorts. The mechanical configuration for the Semi-Works are shown on Drawing 9 in the Appendix Section F.

The top distributors were redesigned following Semi-Works Run SW-5. The 10-inch water-cooled stainless pipe distributors were replaced with 6-inch water-cooled steel pipes to provide a 38% reduction in the resistance to shale flow. The objective of this change was an increase in retort operability for a wide range of process conditions. The results obtained in the demonstration Run SW-7 following the change, were a good indication of the success.

Early Semi-Works runs encountered problems similar to those of the Pilot Plant, with fluctuations in pressure drop across the retort because of changes in the size of the raw shale feed. These variations were closely associated with segregation that was occurring in the shale storage bins. Several changes in operating procedures and equipment including the addition of a polishing screen, drawing 1 of Appendix F, significantly improved the retort operation.

3.6 SEMI-WORKS OPERATING CONDITIONS

In Semi-Works operations, one objective was to demonstrate process operability and another to confirm the design basis for the commercial evaluation portion of the Paraho Oil Shale Demonstration. Concurrent with these operations, the effects of a wide range of process variables were investigated in the Pilot Plant. To demonstrate operability and product yields, operating conditions in the Semi-Works retort were selected from the more promising areas of investigation completed on the Pilot Plant. Therefore, many of the operating

conditions for the Semi-Works were duplications or near duplications of some of the Pilot Retort operations.

As in Pilot Plant operation, lower total air input reduced the oil viscosity and increased the API gravity. Tables 3-5 and 3-6 show periods of stable operating conditions, product yields, and product properties representative of high operability Semi-Works runs.

A complete listing of Semi-Works test data for the direct Heated Mode is presented in Appendix Section D-3 of this report. The test data tabulation presents the results of 70 test periods. Variable investigations were not as extensive as in the Pilot Plant operations but cover a wide range of operating conditions.

A typical particle size consist for Semi-Works operations achieved through the crushing and screening operation is shown by the screen analysis in Tables 3-7 and 3-8. A specific effect on retorting operations is the fines material carried with the primary coarse and screened raw shale feed to the retort. As shown on Table 3-7, 5.1% of the feed material is finer than the 1/2 inch screen being used in the crushing plant. Good retort operation was maintained during Semi-Works Run SW-20 when as much as 8% of the feed material was finer than the 1/2 inch screen.

Included in Table 3-7 are the calculated values Da, Dv, and $\frac{Da}{Dv}$. Da is the area-oriented average particle diameter, ignoring the -8 mesh material. Dv is the volume-oriented

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TABLE 3-5

SEMI-WORKS - DIRECT HEATED MODE OPERATING CONDITIONS AND YIELDS

			OPERATING CONDITIONS					PRODUCT YIELD	
				Air Input					
Run No.	Test No.	Combined Test Length, Hrs.	Mass Rate Lbs/hr/ft^2	Total SCF/T	% To Top Dis	Top & Mid Gas SCF/T	Bottom Gas SCF/T	Oil Collected Wt% F.A.	Gas (Wet) SCF/T
SW-5	A-2	32	422	5,180	67	2,930	15,140	92	8,000
SW-7	A,B,B-1	80	359	5,580	100	3,700	13,870	94	9,190
SW-7	PC-1,2,3	40	404	4,700	67	2,910	14,570	94	5,120
SW-19	A,A-1	32	476	4,410	66	3,150	11,670	91	7,240
SW-20	A-1 - A-5	120	462	4,560	82	2,620	11,820	90	7,030
SW-20	A-9 - A-16	183	448	4,740	82	2,620	11,890	92	7,070

TABLE 3-6

SEMI-WORKS - DIRECT HEATED MODE PRODUCT PROPERTIES

Run No.	Test No.	Combined Test Length, Hrs.	Total Air Input	PRODUCT OIL PROPERTIES Gravity ^{o}API	Vis.SUS @130^{o}F	Ramsbottom Carbon, Wt%	PRODUCT GAS PROPERTIES (Dry) N_2 Vol.%	CO_2 Vol.%	Gross Heating Val BTU/SCF
SW-5	A-2	32	5,180	20.4	120	1.73	62.1	25.7	113
SW-7	A,B,B-1	80	5,580	19.6	146	2.22	61.5	26.1	99
SW-7	PC-1,-2,-3	40	4,700	21.4	95	1.48	64.5	22.6	127
SW-19	A, A-1	32	4,410	21.4	90	2.08	62.7	25.5	129
SW-20	A-1 - A-5	120	4,560	21.3	91	2.22	64.5	24.5	122
SW-20	A-9 - A-16	183	4,740	21.4	88	1.40	66.3	24.0	118

TABLE 3-7

TYPICAL RAW SHALE SCREEN ANALYSIS

Data from Run SW-20

SCREEN ANALYSIS SIZE - INCHES	PASSING - WT%	RETAINED - WT%
2.50	97.9	2.1
2.00	84.8	13.1
1.50	52.0	32.8
1.050	30.3	21.7
0.742	15.0	15.3
0.525	5.1	9.9
0.371	3.7	1.4
0.263	2.4	1.3
0.185	1.9	0.5
0.093	1.2	0.7
PAN	0	1.2

Da = 1.080

Dv = 1.464

Dv/Da = 1.355

TABLE 3-8
TYPICAL RAW SHALE

SCREEN ANALYSIS OF PAN FRACTION

Data from SW-20

SCREEN SIZE	PASSING - WT%	RETAINED - WT%
+8 Mesh	93.95	6.05
+14 Mesh	63.38	30.57
+28 Mesh	44.41	18.97
+48 Mesh	29.16	15.25
+100 Mesh	16.49	12.67
-100 Mesh	0.02	16.47
% Loss		0.02
% of Pan		

NOTE: Analysis of pan fraction only from the 1.2% shown on Table 3-7.

average particle diameter. Correlations of pressure drop, impaction, and yield data versus these values may be used.

The retorted shale particles are quite friable, and therefore, breakage occurs when a sample is run through screen analysis equipment. This should be taken into consideration in reviewing the typical screen analysis shown in Figure 3-1. This figure shows the effect on handling the retorted shale. One sample was collected at the retorted shale sample hopper. Another sample passed through a 15 foot vertical chute to a 30 foot long, 16" diameter screw conveyor and was collected after a 10 foot vertical drop into a drum container.

Data for specific operating conditions and yields representing the Semi-Works Direct Heated Mode of Operation is given in Table 3-9. These data are the average of 13 test periods run at the same conditions. Gas and air flows were held within a 1.5% standard deviation and shale rate within 2.4% between each test. A computer heat and material balance for these composite data is shown in Section 7 under Direct Heated Mode Computer Balances. The corresponding raw and retorted shale properties are shown on Table 3-10.

The product oil recovered and measured in the tanks for the Semi-Works retort were demonstrated as 92 wt% F.A. with a standard deviation of 4.4% between tests during the Semi-Works Run SW-20. This yield was verified by operations totaling 303 hours. Yield value is based on actual recovered oil

TYPICAL RAW AND RETORTED SHALE SIZE DISTRIBUTION

Figure 3-1

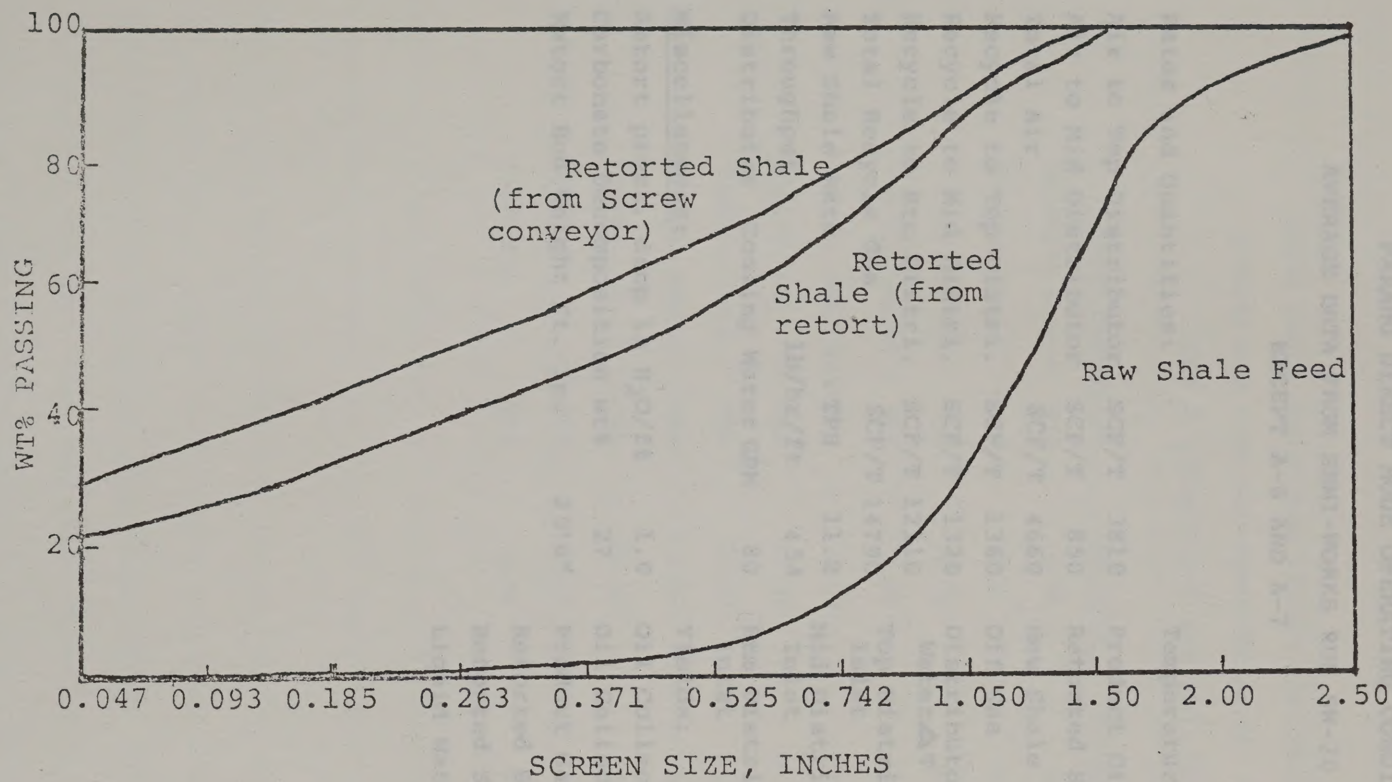

TABLE 3-9

PARAHO DIRECT MODE OPERATING CONDITIONS

AVERAGE DATA FROM SEMI-WORKS RUN SW-20 TEST A

EXCEPT A-6 AND A-7

Rates and Quantities:

Air to Top Distributor	SCF/T	3810
Air to Mid Distributor	SCF/T	850
Total Air	SCF/T	4660
Recycle to Top Distri.	SCF/T	1360
Recycle to Mid Distri.	SCF/T	1320
Recycle to Btm Distri.	SCF/T	12110
Total Recycle Gas	SCF/T	14790
Raw Shale Rate	TPH	11.2
Throughput	lb/hr/ft	454
Distributor Cooling Water	GPM	80

Miscellaneous:

Retort press. drop	in H_2O/ft	1.0
Carbonate Decomposition	wt%	27
Retort Bed Height	Ft. In.	25'6"

Temperatures:

Product Oil	°F	139
Retorted Shale	°F	384
Raw Shale	°F	36
Off Gas	°F	145
Distributor Cooling Water ΔT	°F	18
Top Distributor Inlet	°F	197
Mid Distributor Inlet	°F	212
Btm Distributor Inlet	°F	241

Yields:

Oil Collected	Gal/T	24.8
Oil Collected	Wt% FA	92
Product Gas	SCF/T	7200
Retorted Shale	TPH	9.0
Retorted Shale	wt%RS	81
Liquid Water	lbs/T	9.7

TABLE 3-10

PARAHO DIRECT HEATED MODE PRODUCT PROPERTIES

AVERAGE DATA FROM SEMI-WORKS RUN SW-20

TEST A EXCEPT A-6 AND A-7 (303 Hrs)

Shale Properties		Raw Shale	Retorted Shale
Moisture Content	Wt%	0.96	0.0
Fischer Assay	Gal/T	27.2	0.28
F.A..... Oil	Wt%	10.39	0.10
F.A....Water	Wt%	1.66	0.16
F.A...Gas + Loss	Wt%	2.29	0.29
Mineral CO_2	Wt%	17.71	15.86
Ignition Loss	Wt%	33.07	17.72
Organic Carbon	Wt%	N.A.	1.97
Carbon	Wt%	17.05	6.30
Hydrogen	Wt%	1.84	0.17
Nitrogen	Wt%	0.51	0.21

and does not reflect the naphtha fractions contained in the gas stream at operating temperatures. By adding the C5+ fractions from the product gas as shown by the Paraho Laboratory in the gas analysis, the liquid yield could increase to 96 wt% F.A.

Product gas production for this series of tests measured 7200 SCF/T (wet basis). The heating value on this gas was 118 BTU/SCF on a dry basis. By removing the C5+ fraction from the gas stream, its heating value would be reduced from 118 BTU/SCF (dry) to 91 BTU/SCF (dry). These C5+ fractions comprise only 25 SCF/T, so the total gas quantity is not appreciably changed.

The C5+ fraction is shown in the gas analysis on Table 3-11. This represents an average of the light and heavy naphtha fractions shown by the Paraho Laboratory. This same value was used for all Direct Heated Mode test data presented in the Appendix. The evolution of these gas analyses techniques continued through the entire retorting program.

The calculation of the C5+ fraction is based on the average quantity of light and heavy naphtha fraction shown by the laboratory analysis for Semi-Works Run SW-20 and Pilot Plant Run PP-18. The naphtha fractions for both the Semi-Works and Pilot Plant operations are equal. The heavy naphtha fraction is obtained using a water cooled condenser at approximately 70 ^{o}F which does not remove measureable quantities of hydrocarbons below the C5+ fractions. The light naphthas are

TABLE 3-11
PARAHO DIRECT HEATED MODE PRODUCT PROPERTIES
AVERAGE DATA FROM SEMI-WORKS SW-20
TEST A EXCEPT A-6 AND A-7 (303 HOURS)

Product Oil Properties:			Product Gas Properties (Dry)			
Gravity	^{O}API	21.4	Gross Heat Value BTU/SCF			118
Viscosity SUS @ 130^{O}F		89.9	Specific Gravity			1.10
Viscosity SUS @ 210^{O}F		46.5	Analysis:	H_2	Vol%	2.50
Ramsbottom Carbon wt%		1.73		N_2	Vol%	65.45
Water Content	Vol%	4.46		O_2	Vol%	0.01
Solids, BS	wt%	0.47		CO	Vol%	2.51
Carbon	wt%	84.62		CH_4	Vol%	2.19
Hydrogen	wt%	11.50		CO_2	Vol%	24.14
Nitrogen	wt%	2.00		C_2H_4	Vol%	0.67
				C_2H_6	Vol%	0.62
				C3's	Vol%	0.71
				C4's	Vol%	0.36
				C5's+	Vol%	0.41
				H_2S	Vol%	0.22
				NH_3	Vol%	0.21
			Moisture		Vol%	17.56

obtained in a dry ice-acetone condenser which does remove some fractions, which are also analyzed by the Laboratory Gas Chromatograph (G.C.). A composite value of these naphtha fractions shown as C5+ was calculated by reducing the measured light naphtha fraction by 17% of the average C 3's and 40% of the C4's and all of the C5's shown by the G.C. analysis of the gas. The percentage of light naphtha reduction for the C3's and C4's shown by G.C. analyses was calculated from special analysis of the gas before and after entry to the sub-ambient dry ice-acetone condenser. The adjusted light naphtha value was then ratioed to the heavy naphtha fraction by their respective molecular weights and the combined fraction shown as a C5+ content of the product gas.

Most feed and product properties given in the composite of test data from Semi-Works Run SW-20 are typical of the Direct Heated Mode operations on either retort. Raw shale properties change very little when good blending of mine run shale is maintained. During this run, the raw shale Fischer Assay analysis showed a standard deviation of only 0.27 Gal/Ton.

Oil properties were uniform for Semi-Works Run SW-20. However, minor variations in viscosity, Ramsbottom Carbon, and gravity (°API) have occurred with changes in retort operating conditions during other Semi-Works and Pilot Plant runs. Moisture and sediment contents vary with the raw shale moisture and fines content, retort configuration, insulation of off-gas piping, and ambient conditions.

Gas properties are affected by a change in operating conditions. The increase in carbonate decomposition when a higher SCF/T of air is used, increases the CO_2 and N_2 content, Appendix D-3, Run SW-20, Tests A-5 and B. This results in a dilution of the remainder of the gas. Moisture content of the gas will vary with available moisture from the raw shale and the quantity of product gas being produced. Except for cool sections of the recycle gas system, condensation of moisture should not occur.

3.7 SPECIAL DATA

Special data is defined as that data obtained from non-routine tests run on normal samples (recycle gas, crude oil, and raw and retorted shale). These data are usually not used in material balances and many have not been included in the individual run reports. Special data obtained by the Paraho Laboratory during Direct Heated Mode Operations are summarized in Table 3-12.

During Semi-Works Run SW-20, a special test was made for recycle gas analysis. Representatives from the Atlantic Richfield Company obtained two gas samples using a sub-ambient cold trap technique for complete analysis of all components. The results of their test, Table 3-13, show a higher total hydrocarbon content and a higher heating value of the gas than obtained in the Paraho Laboratory. The gross heating value of the dry product gas based on this analysis would be 162 BTU/SCF as compared to the 118 BTU/SCF previously shown by the Paraho Laboratory Data. If calculated on a C5+

TABLE 3-12

SPECIAL DATA - SEMI-WORKS
DIRECT HEATED MODE OPERATIONS

Sample	SEMI-WORKS	PILOT PLANT
Recycle Gas		
H_2S, Vol%	(18)0.22 ± 0.03	(7)0.27 ± 0.07
NH_3, Vol%	(5)0.20 ± 0.08	(3)0.26 ± 0.15
Raw Shale		
Total S, Wt%	(11)0.63 ± 0.11	(2)0.76 ± 0.03
Retorted Shale		
Total S, Wt%	(11)0.90 ± 0.07	(5)0.80 ± 0.12
Oil		
Total S, Wt%	(14)0.59 ± 0.05	(5) 0.60 ± 0.05
Viscosity, SUS, 100^0F	(18)245 ± 56	----
Mist		
Off-gas		
Lb/MSCF	(4) 5.9	(1) 6.6
Dmmd, μ	2.8	3.0
σg	1.6	1.9
Coalescer		
Lb/MSCF	(3) 3.2	
Dmmd	~2	
ESP		
Lb/MSCF	(4) 0.005	
Blower Discharge		
Lb/MSCF	(2) 0.000	

NOTE: Data are presented as follows: number of tests (in parantheses) followed by mean value plus or minus one standard deviation.

TABLE 3-13

DIRECT MODE PRODUCT GAS ANALYSIS

ANALYSIS BY ATLANTIC RICHFIELD CO. - SEMI-WORKS RUN SW-20

Analysis	Dry Vol%
H_2	4.36
O_2 + Ar	0.92
N_2	64.15
CH_4	2.30
CO	1.98
CO_2	21.75
C_2H_4	0.92
C_2H_6	0.94
C_3H_6	0.45
C_3H_8	0.47
C4's	0.40
C5's	0.16
C6's+	0.77
H_2S	0.22
NH_3	0.21
Moisture Content	17.56
Heating Value (Dry) BTU/SCF	162

basis, it's effect on the potential liquid yield would show a calculated 100 Wt% F.A. recovery.

Contaminants of recycle gas (hydrogen sulfide and ammonia) are listed for both Semi-Works and Pilot Plant. Although the means for ammonia and hydrogen sulfide concentrations are about equal with no significant differences between the Semi-Works and Pilot Plant, the deviations of the individual means are fairly large. This indicates that better data could be obtained by continuous monitoring.

Total sulfur was determined on raw and retorted shale and oil samples retained from five Direct Heated Mode runs. Although no rigorous sulfur balances were made with these data, an approximate overall sulfur balance (including the hydrogen sulfide in the recycle gas) ranges from about 100 to 120%.

Viscosities of Direct Heated Mode crude shale oil were measured at 100^{O}F, primarily for comparison with the Indirect Heated Mode shale oil. The mean Saybolt viscosity at this temperature (245 SUS) is much higher than at 130^{O}F. Significant curvature occurs in the viscosity temperature relationships between temperatures from 100^{O}F to 210^{O}F. This indicates non-Newtonian behavior in this temperature range, probably because the cloud-point has been reached (wax crystallization) at the 100^{O}F.

Mist determinations on Table 3-12 show that there is not significant difference in the loading (#/MSCF), mean

particle size (Dmmd), or geometric deviation (σg) between Semi-Works and Pilot Plants. Mist determinations require isokinetic sampling with minimum flow disturbance lines, therefore, the mist data obtained at the site may not be valid as the flow at the off-gas collector is turbulent. These data show that the Paraho oil separation equipment is effective.

4. INDIRECT MODE

4 INDIRECT HEATED MODE OPERATION

4.1 INTRODUCTION

It has been recognized that the dilution of pyrolysis gas with the products of combustion could be avoided if retort heat requirements were supplied as sensible heat in a recycle gas stream. Gas heating equipment was added to the Pilot Plant and the Semi-Works Retort designs to obtain data using this Indirect Heating. The flow sheet of the Paraho Indirect Heated Mode is illustrated in Appendix Section F (Drawing 3).

4.2 INDIRECT HEATED MODE PROCESS DESCRIPTION

The shale movement and its control through the retort for the Indirect Heated Mode process are the same as for the Direct Heated Mode process previously explained. Gas removal from the bed and the product oil recovery equipment also remain the same.

The primary differences between the Direct and Indirect Heated Modes of operation involve the heating of recycle gas, and those items associated with the high heating value product gas. The quantity of product gas is approximately 1/10th that of the Direct Mode.

A special startup procedure was developed for Indirect Heated Mode operations and is presented in Section 6.2. An inert gas (Pilot Plant Direct Heated Mode gas) is circulated through the external heater and retort

until a suitable heat inventory and temperature profile is established in a moving bed of non-kerogen bearing rock. Then the rock feed is replaced with oil shale and the specified processing conditions are established.

Similar to the Direct Heated Mode, the recycle gas blower compresses the clean gas from the electrostatic precipitator and recycles approximately half to the bottom of the retort and the other half through the external hot gas heaters. Approximately 3% of the gas handled is the product gas which for this program was burned in the thermal oxidizer. Hot gas piping and distributor systems must use alloy steels or other suitable high temperature resistant materials for this operation.

The external heaters that could be timely obtained were not designed for the particular operation and they were proved not to be suitable for heating this high sulfur containing recycle gas. A description of the heaters and associated problems is given in Physical Description, Sec. 5.3.2.

4.3 PILOT PLANT INDIRECT MODE OPERATION

The Pilot Plant preliminary operations in the Indirect Heated Mode defined the characteristics of the gas and the temperatures needed to minimize gas cracking. Due to heater limitations only operator training and process familiarization runs were conducted in the Pilot Plant. The Pilot Plant Operating Summary, Section A of the Appendix, identifies those runs.

The external heaters were made of concentric pipes with the flow of process gas in the annulus. Fins in the annulus were made of Inconel and deteriorated rapidly in the hot gas containing about 3% hydrogen sulfide. Rather than redesigning and refabricating the Pilot Plant external heaters, operations proceeded to the Semi-Works Plant where preliminary heater operations were satisfactory.

4.4 SEMI-WORKS INDIRECT MODE OPERATIONS

The Semi-Works Operating Summary in the Appendix Section B, identifies the Indirect Heated runs. Operability of the Indirect Heated Mode was demonstrated during Semi-Works Run SW-23 with a 31 day operation having a 96.6% on-stream factor. A total of 29 outages were recorded on the heaters accounting for 82% of the time lost. Most of these required less than a 15 minute duration to perform heater re-ignition procedures. In most cases, gas circulation was continued. An additional 18% of the lost time was attributed to two scheduled outages, one for the installation of the bottom recycle gas cooler and another for a raw shale weighbelt check.

The difficulties with the external gas heaters during Semi-Works Run SW-23 were primarily related to the fuel oil burner system and its controls. These problems were corrected, greatly reducing the short-term outages on the heaters.

Metal deterioration problems in the heaters gradually increased throughout the Indirect Heated Mode program. Heater problems indirectly produced process upsets, which in turn limited the operational time on the retort.

The general design problems and limitations of the external heaters are discussed in the Section 5.3.2. The design requirements of gas heaters are well-known and for this reason are not expected to present a serious problem for future installations.

Two unusual operating conditions were noted in the Indirect Heated Mode; a tendency to form a partial blockage of shale flow through the bed and a tendency towards high off-gas temperatures. The latter was not a serious operational problem since the temperature within the collecting system was controlled by the coalescer system.

The problems of partial bed blockage are attributed to the larger diameter distributors required for the Indirect Heated Mode and numerous upsets in process conditions because of heater failure. It was necessary to change the top distributors in the Semi-Works retort back to the original 10-inch pipe size because they were the only distributors available that were suitable for the high temperature service. This increased the bed restriction between the straight side walls and the distributor and increased the gas and shale velocities. This restriction increased the chances of partial blockage to solids flow in this

section of the retort. Generally, partial blockage did not result in a run termination. One effect of a blockage noted was an imbalance between the temperatures of the off-gas ports. Another was the increase in combined off-gas temperature resulting from a decreased bed volume for solids-gas contact.

Operational control for the Indirect Heated Mode differs in many respects from that used for the Direct Heated Mode. Major differences are:

1. Internal temperature changes and their response to process adjustments are much slower in the Indirect Heated Mode because rapid changes in heat inventory are more difficult to make.
2. The position of the hot gas entry is fixed within the bed. In the Direct Heated Mode, however, heat release will move with variations of the combustion zone.
3. Control and operation of the external heater has been added to the plant complexity.
4. Control of temperature of the recycle gas stream is necessary for collection efficiency in the oil collection system and moisture control.
5. Hydrocarbon cracking within the heater is a function of the moisture content of the gas and the temperature of the metal exposed to the gas, and residence time.

Control of the internal process relies primarily on bed temperature measurements and gas analysis. These values

must be used as a guide to adjust prescribed operating conditions of hot gas rate and temperatures.

Control of the external heaters was achieved through an analog instrument system controlling heater outlet temperature; by regulation of the fuel to the heater burner. This sytem was used with a minimum of difficulty during this program.

The volume of product gas made is less in the Indirect Heated Mode. This affects the moisture control of the recycle gas. Moisture content above 50% would result unless water was condensed somewhere within the recycle gas system. With a product gas quantity of approximately 700 SCF/T, or 1/10 that of the Direct Mode, excessively high moisture contents would be required to remove the water as a vapor in the product gas stream.

A special moisture control method was devised for this mode of operation involving a gas cooler and water condenser in the bottom gas recycle stream. By controlling the gas temperature, any desired moisture level could be obtained in that stream. The moisture content in the recycle gas stream could be controlled as desired and was relatively uniform throughout the gas sytem.

Complete temperature control in the recovery system was also accomplished through coolers on the recirculating oil system for the coalescer. As a result, a highly efficient and stabilized operation of the oil-gas recovery

equipment was attained. As in the Direct Heated Mode, a properly insulated system should reduce the water in the product oil to a negligible quantity.

The control of these gas and oil cooling systems was achieved with a simple instrument regulating the flow of cooling water through the heat exchangers. The closed circuit cooling water system was employed as the cooling medium.

The upper temperature limit for hot gas entry was limited by the degree of cracking occurring in the recycle gas stream. It was desireable to maintain a maximum temperature to reduce the quantity of gas required for heat transfer while limiting the degree of cracking. Hydrocarbon cracking must be limited to prevent carbon deposition within the system and to prevent heat loss from its endothermic reactions.

4.5 SEMI-WORKS OPERATING CONDITIONS

While demonstrating the operability of the Indirect Heated Mode, variable studies were also made. A total of 16 test periods were obtained during Run SW-23 under several different operating conditions. The results of these variable studies were used to establish the operating conditions designed to improve retort thermal efficiency for later runs.

The heat input from hot gas affects the product properties and yields in the Indirect Heated Mode in the same manner as heat input in the Direct Heated Mode. When

the heat input is low, the volume of product gas is low, but its unit heating value is higher. At lower heat input, a more fluid oil is produced. Test periods A-4.1 and A-4.2 of Semi-Works Run SW-28 are shown individually on Table 4-1 to illustrate data reproducibility in the Indirect Heated Mode.

With the exception of the external gas heaters, the reliability of all equipment had been previously demonstrated in the Direct Heated Mode operations and was again confirmed in the Indirect Heated Mode operations.

Six operating conditions have been selected from the Semi-Works Indirect Heated Mode to highlight the variations in thermal efficiency and operations demonstrated. The more significant operating conditions are shown in Table 4-1 with the corresponding product properties shown on Table 4-2. Each of the six conditions shown produced a retorted shale having less than 1 gal/ton residual oil by Fischer Assay.

TABLE 4-1

SEMI-WORKS - INDIRECT HEATED MODE OPERATING CONDITIONS AND YIELDS

Run No.	Test No.	Combined Test Length, Hr.	OPERATING CONDITIONS: Mass Rate Lbs/Hr/Ft^2	Hot Gas Input** MBTU/T	Top Dist. Gas SCF/T	Top Dist. Inlet T, $^\circ$F	Bottom Gas, SCF/T	PRODUCT YIELD: Oil, C_5 plus Wt.%F.A.	Gas(wet) C_4 minus SCF/T
SW-23	A-1 thru A-7	152	331	584	18,500	1146	5160	90	1,480
SW-23	C-2.1,-2.2 -2.3	47	504	447	12,370	1176	8460	91	935
SW-23	C-5	16	529	442	11,750	1206	8430	88	1,175
SW-28	C-1, C-2	46	446	440	11,840	1197	7860	90	980
SW-28	A-4.1	12	401	415	11,060	1298	12,570	95	570*
SW-28	A-4.2	24	421	393	10,270	1299	11,650	94	520*

* Gas production may be low because of unmeasured gas leakage through the heater.

** Hot gas heat input at the top distributor inlet temperature, above the 77°F datum.

TABLE 4-2

SEMI-WORKS RETORT - INDIRECT HEATED MODE PRODUCT PROPERTIES

Run No.	Test No.	Combined Test Length, Hrs.	Hot Gas Input MBTU/T	PRODUCT OIL PROPERTIES Gravity $^{\circ}$API	Visc.SUS @ 130°F	Ramsbottom Carbon, Wt%	PRODUCT GAS PROPERTIES (DRY) H_2 Vol%	CO_2 Vol%	Gross Heating Value BTU/SCF
SW-23	A-1 thru A-7	152	584	20.2	108	2.10	26.5	29.2	636
SW-23	C-2.1, -2.2, -2.3	47	447	20.3	90	1.68	26.2	17.2	870
SW-23	C-5	16	442	20.5	90	1.34	25.6	17.1	870
SW-28	C-1,C-2	46	440	21.8	68	1.31	24.9	15.9	886
SW-28	A-4.1	12	415	20.6	83	1.60	25.5	15.5	803
SW-28	A-4.2	24	393	20.0	86	2.10	24.9	15.1	811

4.6 DEMONSTRATION TESTS

Representative operating conditions for the Indirect Heated Mode are shown in Table 4-3. They are average conditions demonstrated in tests A-4.1 and A-4.2 of Semi-Works Run SW-28. These values show a condition of high thermal efficiency as well as good operability.

The scope of process variation in the Indirect Heated Mode as opposed to the Direct Heated Mode, is greatly reduced because of the requirements for high thermal efficiency. Minor variations in the hot recycle gas temperature can be made with the following considerations:

1. The upper temperature limit is determined by the degree of hydrocarbon cracking that occurs. Cracking is also influenced by the moisture content of the recycle gas stream. A control of 30% moisture was maintained during these studies using the bottom recycle gas cooler to remove water from the system.
2. The increase in gas flow required to maintain the desired heat input into the system defines the lower input temperature. The closer this inlet temperature approaches the minimum bed temperature for complete retorting, the greater the gas flow required and the lower the temperature differential between the gas and solids. Total gas flow through the bed is also increased, which is detrimental to the mist formation and causes increased off-gas temperature.

TABLE 4-3

PARAHO INDIRECT HEATED MODE OPERATING CONDITIONS

DATE FROM SEMI-WORKS RUN SW-28

Rates and Quantities:		**Temperature:**	
Recycle to Top Dist. SCF/T	10530	Product Oil °F	147
Recycle to Mid Dist. SCF/T	0	Retorted Shale °F	336
Recycle to Btm. Dist. SCF/T	11950	Raw Shale °F	40
Total Recycle Gas SCF/T	22480	Off-Gas °F	326
Raw Shale Rate TPH	10.2	Top Dist. Inlet °F	1299
Throughput lb/hr/ft	414	Btm Dist. Inlet °F	150
Miscellaneous:		**Yields:**	
Retort Press drop in. H_2O/ft.	1.4	Oil Collected Gal/T	24.2
Carbonate Decomposition Wt%	2.5	Total Oil Yield C5+ Wt% F.A.	95
Retort Bed Height Ft. In.	24"6'	Product Gas SCF/T	535
		Retorted Shale TPH	9.1
		Retorted Shale Wt% RS	89
		Liquid Water Lbs/T	29.9

The yields of oil and product gas in Run SW-28 for the operating conditions are shown in Table 4-3. The 95 Wt% F.A. oil yield, as shown, represents the oil measured in the tank plus the calculated liquid obtained by adding all of the C5's and heavier naphtha fractions in the product gas stream going to the thermal oxidizer. The recovered oil without this naphtha addition was 93.5 wt% of F.A.

The product gas production for these two test periods (Run SW-28, A-4.1 and A-4.2) measured 535 SCF/T on a wet basis. Possible internal process gas leaks may have occurred in the heater during this period thus reducing the measured product gas yield. This loss is indicated by comparing these results to those of other Indirect Heated Mode tests.

The shale properties for the preceding tests are shown in Table 4-4 and product properties in Table 4-5.

The computer program balances shown in Section 7.2 Table 7-20 are based on raw shale weights and ash contents. Included as part of the computer program is the heat balance for the retort. This shows a hot gas input of 402 MBTU/T at the top distributor based on the 77°F datum temperature. The corresponding heat requirement based on gas blower discharge temperature of 214°F to the gas distributor inlet temperature of 1299°F is 378 MBTU/T.

The yields of oil and product gas in Run SW-28 for the operating conditions are shown in Table 4-3. The 95 Wt% F.A. oil yield, as shown, represents the oil measured in the tank plus the calculated liquid obtained by adding all of the C5's and heavier naphtha fractions in the product gas stream going to the thermal oxidizer. The recovered oil without this naphtha addition was 93.5 wt% of F.A.

The product gas production for these two test periods (Run SW-28, A-4.1 and A-4.2) measured 535 SCF/T on a wet basis. Possible internal process gas leaks may have occurred in the heater during this period thus reducing the measured product gas yield. This loss is indicated by comparing these results to those of other Indirect Heated Mode tests.

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TABLE 4-4

PARAHO INDIRECT HEATED MODE SHALE PROPERTIES

DATA FROM SEMI-WORKS RUN SW-28

Shale Properties		Raw Shale	Retorted Shale
Moisture Content	Wt%	1.23	0.0
Fischer Assay	Gal/T	26.3	0.50
F.A. ...Oil	Wt%	10.02	0.19
F.A. ...Water	Wt%	1.68	0.74
F.A. ...Gas + Loss	Wt%	2.03	0.62
Mineral CO_2	Wt%	17.70	19.47
Ignition Loss	Wt%	32.02	23.32
Organic Carbon	Wt%	11.77	3.06
Carbon	Wt%	16.16	8.37
Hydrogen	Wt%	1.70	0.33
Nitrogen	Wt%	0.45	0.34

TABLE 4-5

PARAHO INDIRECT HEATED MODE PRODUCT PROPERTIES

DATA FROM SEMI-WORKS RUN SW-28

Product Oil Properties:		Product Gas Properties: (Dry)	
Gravity, Deg API	20.2	Gross Heat Value BTU/SCF	808
Viscosity SUS @ 130°F	85.0	Specific Gravity	0.721
Viscosity SUS @ 210°F	45.7	Analysis: H_2 Vol%	25.12
Ramsbottom Carbon Wt%	1.93	N_2 Vol%	0.56
Water Content Vol%	1.07	O_2 Vol%	0.0
Solids, B.S. Wt%	1.56	CO Vol%	2.73
Carbon Wt%	84.89	CH_4 Vol%	32.15
Hydrogen Wt%	11.44	CO_2 Vol%	15.24
Nitrogen Wt%	2.03	C_2H_4 Vol%	12.74
		C_2H_6 Vol%	4.52
		C3's Vol%	2.28
		C4's Vol%	0.61
		H_2S Vol%	2.82
		NH_3 Vol%	1.23
		Moisture Vol%	28.82

4.7 PRODUCT PROPERTIES

Product properties show only minor changes with operating conditions. The changes in gas composition are the most significant, occurring from both carbonate decomposition and hydrocarbon cracking from increased distributor inlet temperatures. This can be seen in the complete tabulation of Indirect Heated Mode data in the Appendix D-3.

The Indirect Heated Mode product oil quality has shown lower viscosities than the Direct Heated Mode operations. Viscosities decrease with reductions in retort bed temperatures and increased efficiency of operation. Other associated oil properties such as pour point and API gravity also improve with lower viscosities as previously shown in Tables 4-1 and 4-2.

Retorted shale has a relatively high residual carbon and shows little change unless a condition of incomplete retorting occurs due to inadequate heat input or insufficient temperature. Some test periods shown for the Indirect Heated Mode reflect this condition, see Appendix Section D-3, Tests; SW-22 A-2; SW-28 Step 3, A-3, A-4 and A-4.4.

4.8 SPECIAL DATA

During Semi-Works Run SW-28 test period A-4.1, a special large size gas sample stream was processed for complete analysis of recycle gas. Representatives from the Atlantic Richfield Company obtained two gas samples using the

same techniques they employed during Direct Heated Semi-Works Run SW-20. The amounts of cold trap condensates were significantly greater than shown by the Paraho control laboratory. The values are shown in Table 4-6 are an average of the two tests and include the H_2S and NH_3 values obtained by the Paraho Laboratory. The increase in the C5+ naphtha fractions represent an increase of 226 BTU/SCF in the gross heating value of the product gas on a dry basis. The effect on the liquid yield is most significant, raising the C5+ yield from the 95% shown to 98 wt% F.A. Therefore, all of the C5+ yields given in the Appendix, Section D-3, may be 3 wt% low as the data reported are based on the Paraho control laboratory analyses. This change will also affect the hydrocarbon balances.

Special Paraho Laboratory data obtained during Semi-Works Indirect Heated Mode operations are shown in Table 4-7. Included are recycle gas contaminants (H_2S and NH_3), total sulfur, and Saybolt viscosities at $100^{\circ}F$.

As in the case of Direct Heated Mode operation, the levels of hydrogen sulfide and ammonia are approximately equal. Both modes of operation have large deviations including wide fluctuations in the levels from time to time.

Total sulfur data was obtained for crude oil and raw and retorted shale from two Indirect Heated Mode runs. These data do not differ significantly from Direct Heated Mode data.

TABLE 4-6

INDIRECT HEATED MODE PRODUCT GAS ANALYSIS

ANALYSIS BY ATLANTIC RICHFIELD COMPANY

SEMI-WORKS RUN SW-28 TEST A-4.1

Product Gas Properties (Dry Basis)	
Gross Heating Value	1036
Specific Gravity	.866
Analysis:	
H_2 Vol%	22.95
N_2 Vol%	0.38
O_2 Vol%	0.01
CO Vol%	2.71
CH_4 Vol%	30.20
CO_2 Vol%	14.79
C_2H_4 Vol%	11.34
C_2H_6 Vol%	5.58
C_3's Vol%	3.03
C_4's Vol%	0.77
C_5's Vol%	0.16
C_6's+ Vol%	4.20
H_2S Vol%	2.71
NH_3 Vol%	1.16

TABLE 4-7

SPECIAL DATA SEMI-WORKS INDIRECT HEATED MODE OPERATIONS

Recycle Gas		
H_2S,	Vol%	(9) 2.07 ± 0.33
NH_3,	Vol%	(5) 2.02 ± 1.31
Raw Shale		
S,	Wt%	(3) 0.79 ± 0.03
Ret Shale		
S,	Wt%	(3) 0.74 ± 0.15
Oil		
S,	Wt%	(13) 0.62 ± 0.05
SUS, 100°F		(18) 192 ± 55

NOTE: Data are presented as follows: number of tests (in parentheses) followed by mean values plus or minus one standard deviation.

Saybolt viscosities were determined at $100^{\circ}F$ on the Indirect Heated Mode crude shale oil. The mean data (192 SUS) are not significantly reduced from the Direct Heated Mode data and some curvature still exists in the viscosity - temperature relationship from $100^{\circ}F$ to $210^{\circ}F$.

An attempt was made to determine mist characteristics during Indirect Heated Mode operations. Probes fitted with packing glands and gate valves were installed during a retort outage because of potential hazards, due to the flammability and toxicity of indirect recycle gas. However, the small opening in the probe tips plugged and no valid samples were obtained.

5. EQUIPMENT DESCRIPTION

5. PHYSICAL DESCRIPTION

5.1 DESCRIPTION OF PILOT PLANT

The Pilot Plant was constructed to explore the broad process parameters for the retorting process. The results of these studies provided the basis for the confirmation and demonstration runs in the Semi-Works retort.

The Pilot retort has a 1/4-inch mild steel plate shell of 4 1/2-foot outside diameter with an insulating lining, detailed in Appendix E. The inside diameter is 2 1/2-feet and the cross-sectional area inside the lining is 4.909 square feet.

The height of the retort vessel (from the retarder plate in the grate mechanism to the bottom of the raw shale level hopper) is 33.1 feet. The working bed height is adjustable. The overall height (from ground level to the upper rotary seal) is about 58 feet.

A cross-sectional diagram showing the retort dimensions and the position of the rotary seals, off-gas collector, distributors, and grate mechanism is shown on Drawing 8.

The solids handling system (Drawing 2) shows the flow of material for both Pilot and Semi-Works plant starting with the conveying system from the shale storage area. Crushed shale may be supplied from any one, or any combination, of four storage bins to a primary feed conveyor. As the crushed shale

leaves the primary belt conveyor, it passes over a motorized diversion gate used for sampling the raw shale for either Pilot or Semi-Works plants. Descriptions of the sampling systems are in the Laboratory Report. The crushed shale flows through the sampler gate to a short reversible belt conveyor that is used to divert the shale supply to either retort surge hopper. The shale is withdrawn continuously from each surge hopper by a vibrating feeder - weigh conveyor system and fed to the top of the retort.

The raw shale level control hopper on the top of the retort is used as a surge between the weighbelt conveyor and the retort. Shale feed rates are adjusted to maintain a constant level in the raw shale feed hopper. The hopper has a surge capacity of approximately one ton of material. The retort mass rate is controlled by the hydraulically operated grate at the bottom of the retort. Correlations of grate strokes and raw shale feed rates serve as a guide to establish a steady processing rate with only occasional adjustments.

The raw shale descends from the level control hopper, through a telescoping chute arrangement that is used for bed height adjustment within the retort vessel and into the retort. As the shale moves through the various zones, it passes around the top and mid distributors within the retort and continues to the discharge grate at the bottom of the retort.

The details of construction for the level control

hopper and telescoping adjustment system are on the retort cross-sectional drawing (Drawing 8).

The discharge grate mechansim consists of two side baffles used for bottom recycle gas entry and one pusher bar mechanism set on the single retarder plate. The retarder plate prevents free flow of material out of the retort. Shale discharge will only occur with reciprocal movement of the pusher bar. Sloping plates guide the shale bed toward the pusher bar which is alternately pulled by a hydraulic cylinder from each side of the retort. The pusher profile is carefully contoured to cause a laterally uniform descent of the shale throughout the retort cross-section. As the material is discharged from the retarder plate, it drops into a collection cone at the bottom of the retort. From there, the retorted shale passes through a double rotary seal system and drops onto the retorted shale conveyors. The rotary seals at the bottom of the retort act to retain internal gas pressure while discharging retorted shale. A purge gas is installed between the two rotors to assist in preventing leakage of gases through the seals.

As the retorted shale leaves the double rotary seals, it drops onto an inclined weighbelt conveyor, past a diversion gate for sampling, and to the disposal conveying system. This retorted shale weighbelt is similar to the raw shale feed weighbelt. Retorted shale from both the Pilot and Semi-Works retorts join to a common disposal conveying system as shown in Drawing 2. An alternate bypass chute arrangement was installed to provide an alternate method of

hopper and telescoping adjustment system are on the retort cross-sectional drawing (Drawing 8).

The discharge grate mechanism consists of two side baffles used for bottom recycle gas entry and one pusher bar mechanism set on the single retarder plate. The retarder plate prevents free flow of material out of the retort. Shale discharge will only occur with reciprocal movement of the pusher bar. Sloping plates guide the shale bed toward the pusher bar which is alternately pulled by a hydraulic cylinder from each side of the retort. The pusher profile is carefully contoured to cause a laterally uniform descent of the shale throughout the retort cross-section. As the material is discharged from the retarder plate, it drops into a collection cone at the bottom of the retort. From there, the retorted shale passes through a double rotary seal system and drops onto the retorted shale conveyors. The rotary seals at the bottom of the retort act to retain internal gas pressure while discharging retorted shale. A purge gas is installed between the two rotors to assist in preventing leakage of gases through the seals.

As the retorted shale leaves the double rotary seals, it drops onto an inclined weighbelt conveyor, past a diversion gate for sampling, and to the disposal conveying system. This retorted shale weighbelt is similar to the raw shale feed weighbelt. Retorted shale from both the Pilot and Semi-Works retorts join to a common disposal conveying system as shown in Drawing 2. An alternate bypass chute arrangement was installed to provide an alternate method of

retorted shale disposal through the sampling system and out to a screw conveyor to the retorted shale disposal pile. During the use of this bypass arrangement (required for separating the retorted shale from both retorts during a simultaneous operation), sampling of the retorted shale can be accomplished only by grab samples rather than the usual continuous and automatic sampling operations.

The gas handling system for the Pilot Plant is shown on Drawing 3. Off gases from the shale bed leave the shale interface between the telescoping feed chute and the retort wall and are removed at a single collection point through a six-inch off gas line at the top of the retort. Using a pressure tap in the off gas line, a pressure controller adjusts the product gas valve position to maintain a slight positive pressure in the top of the retort. The off-gas containing oil mist passes through the six-inch line to the coalescer and then to the electrostatic precipitator for oil separation from the gas.

Clean recycle gas is piped to the suction of the seven stage Hoffman recycle blower and pressurized. The discharge of the recycle gas blower is diverted to four different lines for measurement and control; the bottom recycle gas line, the mid and top distributor gas lines, and the product gas vent line going to the thermal oxidizer. A common upstream pressure tap and temperature measurement is taken for these orifice runs. Each control loop consists of a controller, a throttle butterfly valve, and an orifice.

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A seven stage Spencer blower using a suction filter supplies air for combustion purposes at all three distributors levels. Similar to the recycle system, the discharge of this blower is diverted to three lines of the bottom, mid, and top distributors for air supply. A common upstream pressure tap and thermocouple are used for all orifice runs and a butterfly control valve maintains positive flow control for each air entry point. Air is injected into the recycle gas lines for mixing prior to its entry into the distributors. A high velocity injection nozzle is used for this purpose.

For Indirect Heated Mode operations, the gas lines to the mid and top distributors are diverted through two vertical external gas heaters before entering each distributor. Arrangements for the Indirect Heated Mode operations are made using a system of blinds to divert the gas stream through the heater system. All materials of construction downstream of the heaters are of 304 stainless steel to provide temperature and corrosion resistance for hot gas operation.

The distributor system in the Pilot Plant consists of a single 4-inch stainless steel pipe using a row of injection orifices on each side of the pipe for proper gas distribution. A common circulating cooling water system is used to maintain temperature control of these distributors for Direct Heated Mode operation. During Indirect Heated operations, the distributor water cooling system is drained and vented to prevent cooling of the hot gases being supplied

A seven stage Spencer blower using a suction filter supplies air for combustion purposes at all three distributors levels. Similar to the recycle system, the discharge of this blower is diverted to three lines of the bottom, mid, and top distributors for air supply. A common upstream pressure tap and thermocouple are used for all orifice runs and a butterfly control valve maintains positive flow control for each air entry point. Air is injected into the recycle gas lines for mixing prior to its entry into the distributors. A high velocity injection nozzle is used for this purpose.

For Indirect Heated Mode operations, the gas lines to the mid and top distributors are diverted through two vertical external gas heaters before entering each distributor. Arrangements for the Indirect Heated Mode operations are made using a system of blinds to divert the gas stream through the heater system. All materials of construction downstream of the heaters are of 304 stainless steel to provide temperature and corrosion resistance for hot gas operation.

The distributor system in the Pilot Plant consists of a single 4-inch stainless steel pipe using a row of injection orifices on each side of the pipe for proper gas distribution. A common circulating cooling water system is used to maintain temperature control of these distributors for Direct Heated Mode operation. During Indirect Heated operations, the distributor water cooling system is drained and vented to prevent cooling of the hot gases being supplied

from the external heater.

The mist separation and oil recovery for the Pilot Plant include a coalescer and electrostatic precipitator. The coalescer system is designed to remove about half of the mist prior to the final cleanup in the electrostatic precipitator. The coalescer, consisting of a system of sprays followed by a knockout chamber, removes mist from the gas stream with negligible pressure loss (Drawing 11). The electrostatic precipitator is a wet type unit originally purchased by the U.S. Bureau of Mines in the 1950's. It was installed to remove oil mist for the Pilot Plant operation. During proper operation, oil recovery, determined from mist analysis, exceeded 99%. An accumulation of oil within the coalescer recirculating tank overflows by gravity and joins the electrostatic precipitator product stream going to storage. A gravity oil drain and sealing system equipped with heat tracing and insulation to two rundown tanks is used for both the electrostatic precipitator and the coalescer. Two rundown tanks are employed for the Pilot Plant, each having a cone bottom and a capacity of approximately 35 barrels (about one day's operation at high shale rates).

Instrumentation for the Pilot Plant, shown on Drawing 3, includes a temperature-pressure probe device within the retort bed for measurement for bed temperature and pressures. This temperature-pressure probe consists of a two-inch stainless pipe equipped with 14 thermocouples spaced at two-foot intervals and five pressure points as shown on the retort cross-sectional

from the external heater.

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diagram (Drawing 8). These bed temperatures and other gas and oil temperatures throughout the Pilot Plant are recorded on multi-point strip chart recorders. Bed pressures and orifice differential pressure leads are connected to manometers on the control panel. All gas and air flows are recorded on miniature circular charts in the analog controllers on the control panel. The manometer readings, weight counter readings, and many temperatures are recorded hourly in the control room by the retort operators. Cooling water rates are measured and temperatures in and out of the distributors recorded for calculation of heat loss to the cooling water.

The hydraulic circuitry includes an electrical alarm on a delay relay to indicate grate stoppage. Electrical interlocking is used to turn off the air blower when the recycle gas blower fails. A secondary override for the air blower is tied to the startup propane valve to prevent propane injection during startup periods in case of air blower failure.

An on-line gas chromatograph, a continuous oxygen analyzer and an Orsat apparatus are used to monitor components of the recycle gas. A switchover system permits monitoring Pilot or Semi-Works operations. An on-line gas chromatograph continuously monitors these gases: oxygen, nitrogen, carbon monoxide, carbon dioxide, methane, ethylene, and ethane in the recycle gas stream. Attenuator switches permit monitoring of the gas in either the Direct or Indirect Heated Mode of operation.

5.2 DESCRIPTION OF SEMI-WORKS PLANT

The Semi-Works Plant was used to provide data for commercial evaluation and design basis. Selected operating conditions on the retort was used to demonstrate and confirm the design criteria used for the commercial evaluation.

The retort is shown in Drawing 9, and detailed in Appendix E. It is a 10 1/2-foot O.D. cylindrical vessel having an outer shell of 1/4-inch steel plate. The 1-foot thick retort lining has been altered from a circular cross-section to provide flat walls parallel to the air-gas distributors. The circular section has an internal diameter of 8 1/2-feet and the flat walls are 6 1/2-feet apart giving an unrestricted cross-sectional area of 49.25 square feet.

The retort construction, auxiliary equipment and instrumentation are similar to that of the Pilot Plant and unless otherwise stated the equipment function and description will be the same.

The increased retort diameter requires two air-gas distributors at each level and two parallel pusher bars for the grate discharge mechanism. The height of the retort vessel (from retarder plate in the grate mechanism to the bottom of the raw shale level hopper) is 41 1/2-feet and the overall height is about 72 feet.

The retorts use a common raw shale supply system from the storage bins through the raw shale sampler to the surge hoppers (see Drawing 2). The raw shale surge hopper for the Semi-Works retort contains approximately a two-hour shale supply for normal operations. Shale level is controlled with a high level shutoff switch to the feed conveying system and a low level alarm system.

Shale leaving the surge hopper passes over the vibrating feeder to a bucket elevator which feeds a second small surge bin. The small surge bin (only a few minutes capacity) for the elevator discharge is used to supply the vibrating feeder which feeds the raw shale weighbelt. A high and low level control is used to maintain a shale level in this small surge bin. The weighbelt-feeder system for the Semi-Works unit operates similarly, but its capacity is approximately ten times greater than the Pilot Plant.

A diversion chute from the Semi-Works weighbelt conveyor provides a method of weight calibration and check by routing the shale to a truck for weighing. Under normal operations, the discharge from the weighbelt conveyor passes directly to the top rotary seal and into the level control hopper at the top of the retort.

The level control hopper for the Semi-Works retort discharges into a rotating solids distributor which spreads shale across the full diameter of the retort to control particle size segregation as the shale enters the retort.

Solids flow around submerged off-gas collectors and descend through the Semi-Works retort as previously explained in the Pilot Plant description. The Semi-Works retort differs from the Pilot retort in that it uses submerged off-gas collectors and has two distributors for the top and middle air-gas entries and two parallel pusher bars and retarder plates for the discharge grate mechanism. In the bottom of the retort, there is a single retorted shale collecting cone and a double rotary seal assembly. The retorted shale discharges from the retort onto a retorted shale weighbelt, and from there to the retorted shale sampling and disposal system.

Two parallel off-gas collectors are installed across the retort bed normal to the straight sidewalls. They are half-pipes with vertical skirts extending downward to effectively cause the gases to exit the shale lump surface and enter off-gas ports. The ports are manifolded and are joined in a Y to a single pipe leading to the oil recovery equipment. Temperatures are recorded from each of the four discharge ports. The single pipe contains a thermocouple which represents a composite of the individual port temperatures. After leaving the oil separation equipment, the recycle gas is compressed in a seven-stage blower for distribution to the recycle system as shown in Drawing 4. For the Direct Heated Mode, another seven-stage blower is used to supply air for injection into the gas lines.

The gas heating equipment for supplying hot gas for the Indirect Heated Mode operations is similar in function but of different design than that employed for the Pilot Plant. The Semi-Works external heaters are fired with No. 2 fuel oil and have six horizontal tube banks, designed to heat the gas to 1400°F. An additional change for Indirect Heated Mode operations in the Semi-Works unit was the installation of the gas cooler - knockout pot arrangement for the bottom recycle gas. The function of this is to control the water vapor in the gas going to the heater by condensing and removing water from the system. A temperature controller is used to measure downstream gas temperature and to control the flow of cooling water to the water jacket of the cooler.

The product gas is burned in the thermal oxidizer. During the Indirect Heated Mode operation, the volume of product gas was much less than the Direct Heated Mode and therefore a small control valve was used on the product gas line.

The oil recovery system for the Semi-Works retort is of similar design, construction, and operation as that in the Pilot retort. A number of minor differences in the piping were made to remove oil from both the electrostatic precipitator and coalescer. These differences are shown on Drawings 4 and 5. Rundown tanks for the Semi-Works retort each provide capacity for about eight hours of operation. For details of the shale oil rundown and storage system, see Section 5.4 Auxiliary Systems.

The temperature - pressure probe used in the Semi-Works retort is located as shown on Drawing 9 and the gas analysis equipment is manifolded so that the gas can be analyzed from either plant.

5.3 MATERIALS HANDLING EQUIPMENT

This section describes the equipment as well as limitations of the solids, gas and oil handling systems of the Pilot and Semi-Works plants.

5.3.1 SOLIDS

Raw shale preparation includes the stockpiles and primary crushing and screening through the storage and distribution system as shown on Drawing 1. This complex was installed in 1946 and because deliveries of desired equipment were so long, it was necessary to use the equipment that was available, most of which was old and in poor condition. The system cannot adequately control particle shape factor or size distribution. Primary crushing is accomplished in a Blake jaw crusher, built in 1919, which reduces material to approximately 5 inch maximum lump size. From there, the crushed shale is conveyed to a double deck primary screen. The oversized material is crushed in a secondary double roll tooth crusher. Products from the secondary crusher are recycled back over the screen to acquire the size product specified for retort operations. By varying screen size and crusher settings, feed material from a top size of 1 1/2 to 4-inches is produced in this crushing and screening operation. The undersize material is removed as desired by the lower deck screen and discarded to a fines pile.

The sized shale from the screen is transported by a system of belt conveyors to four storage bins consisting

of three 80-ton bins with cone bottoms and one 1,000-ton bin. Shale removal from the 80-ton storage bins is accomplished with vibrating feeders equipped with perforated decks for fines removal and the 1000-ton bin equipped with a vibrating feeder without fines removal equipment.

The shale is transported from the feeders by belt conveyors to a polishing screen where fines are removed prior to being conveyed to the retort surge hoppers. The fines waste belt conveyor from the bin discharge feeders is also used for emptying or recirculating the bins. All bin discharge and conveying equipment is controlled from the retort control room, thus providing complete flexibility in blending or switching bins.

The variation in screen analysis of the retort feed is used to evaluate the crushing operation performance and to control crusher maintenance and adjustment.

A primary requirement of retorting operations involving crushed and screened material is the proper control of particle size distribution. Even though crushing and screening facilities may provide a properly sized raw shale product, this size distribution must be maintained through storage and handling facilities to achieve a minimum of variation in the actual feed to the retort. To meet the tonnage requirements for retorting, it was necessary to make maximum use of available shale storage facilities even though problems of particle size

segregation existed in the bins. Particle size segregation occurred while filling and emptying the four storage bins. A system of baffles installed in the bottom of the 80-ton storage bins aggravated this problem and retained fines which could be removed only after a complete emptying of the bins. Particle size segregation problems were also detected in the surge bins at the Pilot and Semi-Works retorts and within the level control bins at the top of the retorts. The surge bins feed arrangement was changed and the level control mechanism within the retort feed bins was repositioned, which alleviated some of the segregation problems.

An associated problem with particle size segregation involves shale with high surface moisture. Due to lack of enclosed storage, the mine run shale is trucked to a large open area stockpile before feeding the crusher. This open storage pile is exposed to all weather conditions, the worst of which can cause serious problems. The natural adhesion character of the wetted fines cause them to stick to the larger particles and be carried through the system and into the retort. This in turn causes high retort pressure drop together with restricting the gas piping flow and contaminating the product oil.

The following additional problems were experienced in the old plant:

1. Excessive maintenance on old equipment
2. Inadequate storage capacity

3. Inadequate crushing capacity
4. Screen inefficiency
5. Design restriction for additional equipment

Under item 5, the surge bins for the Pilot and Semi-Works plants were designed into the existing retort structure used for former operations. These restrictions resulted in a poor design that contributed to segregation of particles.

Fines, surface moisture and particle size segregation were shown to affect retort operations. However, the retort tolerance of these effects was proved in a 56 day run in the Semi-Works retort through the severe winter weather conditions.

Particle size segregation always occurs when a mixture of different sizes of particles is allowed to seek its angle of repose. Segregation also occurs during a gravitational flow in passing from a smaller to a larger cross-sectional area. This principle is present in the Pilot retort telescoping chute feeding device but caused only minor particle segregation due to a small change in diameter between the telescoping chute and the retort. The effects are not evident in the data or operation.

The Semi-Works rotary solids distributor assembly consists of four feeder legs. One pair of legs places the shale in a ring near the retort wall and the other pair places the shale in a ring near the center of the retort. This minimizes segregation in the flow of shale from the

smaller hopper into the larger retort cross-section, but will not correct for particle size variation in the feed to the retort.

The linear grate mechanism installed in both Pilot and Semi-Works retorts controls the solids flow throughout the retort cross-section.

The results of cold flow tests made with typical retort feed in both retorts confirmed the uniform movement of solids. The initial tests in the Pilot retort confirmed the residence time of particles moving through the bed is independent of particle size or position within the retort. In the first Semi-Works cold flow test, the standard deviation of all particle residence times was 7.6%. A portion of this variance was caused by the slower movement of the shale adjacent to the straight sidewalls of the retort. The pusher bar contour was modified and a subsequent cold flow test showed a standard deviation of all particle size residence times at 4.2%, an overall improvement over the first test. This standard deviation compares favorably with the Pilot Plant value of 4.3% for all particle size residence times.

Operational experience of the grate mechanism on both retorts uncovered some problems that required adjustment and alterations during the program. Problems with early unstable control of the discharge mechanism were traced to initial design of the hydraulic system. Pressure loss in the hydraulic line from the hydraulic supply system to the retort was being affected by variation in the ambient

temperature and uninsulated lines. This was corrected by proper tracing and insulating of the system. A problem of flow restriction was caused by undersized lines. Larger hydraulic lines were installed which corrected this problem.

During the early runs on both the Semi-Works and Pilot Plants, frequent failures of hydraulic cylinder seals and packing occurred. This problem was traced to a buildup of material on the piston rods that was not removed by the rod seal/wipers. A laboratory analysis of the material indicated the presence of magnetic iron dust as one of the contributing components of this buildup material. An extension box was mounted between the hydraulic cylinders and the retort discharge cone. A new sealing arrangement to prevent gas leakage was constructed around this connecting rod assembly. The failures of hydraulic cylinder seals caused three runs in the retort to terminate.

After revisions, the Semi-Works plant completed 122 days of actual retort operations with only two outages due to hydraulic cylinder problems.

The rotary seals limited the size of material that could be fed to the retorts as they will pass only minus 3-inch raw shale. During Semi-Works Runs SW-14 through SW-18, 3 1/2-inch raw shale was processed by removing the rotor in the top rotary seal. The retort was filled with 2 3/4-inch shale to protect the lower rotary seals during start-up. The 3 1/2-inch shale was then added. Once retorted, 3 1/2-inch material passes through the bottom rotary seals

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with no problems.

In early operations, occasional overload due to shale particles locking in the top rotary seals caused drive shear pins to fail. A delay in feeding operations resulted until a new pin could be manually installed. To decrease these interruptions, the seals were equipped with momentary torque limiting electrical overload protection having automatic reset, manual reversing switches, and coupled with an alarm. Through this improvement, the operator could remotely operate the seal and relieve the blockage without leaving the control room.

High wear rates were experienced with the original rotary seals in the Semi-Works retort prior to Run SW-12. The original rotary seals in the retorted shale service were replaced with newly designed double rotary seals having a low rate air purge to the endbells. There were no further problems with the seals.

The handling of retorted shale from the rotary seal discharge to disposal was by a system of conveyors and chutes. Much of the retorted shale was loaded into trucks and transported to the retorted shale management research area. The remainder was placed in the disposal canyon. A stacker conveyor was added during the changes proceeding Semi-Works SW-12. The conveyor is equipped with a motorized swivel movement system that greatly reduced the direct handling requirements for retorted shale disposal.

Dry type dust collection that is properly designed and installed works quite successfully controlling retorted shale dust. Retorted shale dust can be adequately controlled by either confinement or dry type dust collection in all areas. Fugitive dust from the disposal pile is not a specific problem. A minor problem of dust picked up by a thermal draft did exist on the disposal pile caused by a stream of warm retorted shale moving down the angle of repose on the pile. This can also be controlled with dry type dust collection except during periods of excessive wind conditions.

The retorted shale weighbelt presented many difficulties throughout the program. Intermittent high temperatures caused by upset operating conditions resulted in belt expansion and deterioration which affected the accuracy of the weight measurements. Test data presented in this report uses the raw shale weights and the ash measurements in the raw and retorted shales to calculate the retorted shale weights whenever the measured weight causes the ash balance to be outside the range of 99-101 weight percent.

5.3.2 GAS

The Pilot and Semi-Works retorts are equipped with rotary seals to allow shale into and out of the retort and minimize leakage of air into or gas out. During Semi-Works Runs SW-14 through SW-18, the rotor was removed from

the top seal to accommodate larger size shale feed. Control of air in-leakage and product gas loss was attempted using top pressure control. Because of the gas valve actions, this control was not adequate and the rotor was again installed in the seal.

Gas loss through the rotary seals varies with wear to the seals and operating conditions. A method was developed to measure these gas losses from both the top and bottom rotary seals. In this report, the gas loss through the rotary seal has been added to the product gas quantities for Indirect Heated Mode data. The data does not account for the proportionately small seal loss in the Direct Heated Mode.

Bed height adjustment in the Semi-Works retort is made by the addition of extension skirts to the off-gas collectors. In the Pilot retort, an adjustment of the telescoping shale feed chute is used for this purpose.

After leaving the retort, the recycle gas passes through the oil mist recovery equipment to the recycle gas blower. All major piping and vessels between the retort and suction of the recycle blower was insulated to prevent exposure to extreme weather conditions. A foam type insulation was used to prevent condensation of moisture thus reducing the moisture content of the product oil. A substantial decrease in water content of the product oil was shown following insulation of the pipes.

The recycle blowers are multi-staged and capable of developing 150 inches of water discharge pressure. All blowers are generally operated below design capacity and often below their cyclic surge line. To prevent surging within the blower at low capacity, a bypass system is used to recycle a portion of the gas from the discharge back to the suction stage. Both Pilot and Semi-Works blowers are operated without their suction stage impellers to reduce excess pressure and compression temperature rise.

A liquid removal system is required on each blower stage to keep the blower free of collected water and oil. To alleviate this problem, a line skimmer removes the liquid flowing along the pipe surface immediately before its entry into the blower. Both the skimmer and the individual blower stage drains are then piped to the rundown tanks for measurement and sampling.

The Semi-Works recycle blower was dismantled for inspection only once during the program and accumulated sludge and polymerized oil were removed. This was done prior to Run SW-12.

The pressure requirements for the recycle system generally are small compared to the pressure available from the blower. The individual pressure drops under typical Direct or Indirect Heated operations on the Semi-Works retort are shown in the following table 5-1.

TABLE 5-1

PRESSURE DROP THROUGH THE RECYCLE GAS SYSTEM

	Direct	Indirect
	In. of H_2O	In. of H_2O
Retort Shale Bed	26"	26"
Top of Shale Bed to Recycle Blower Suction	1 to 2"	6 to 8"
Permanent Loss caused by Orifice Differential	2 to 12"	2 to 12"
Control Valve	Variable	Variable
Gas Heater	---	8"
Distributor Piping and Entry	2 to 10"	2 to 10"
TOTAL - Maximum Total Less Control Valve	50"	64"

The heating of recycle gas in the Indirect Heated Mode is achieved in the multi-tube, six pass, horizontal heaters for the Semi-Works retort. For the Pilot retort, a vertical single pass, alloy steel, finned - tube heater was used. Many problems occurred with their operation which greatly limited operational time in the Indirect Heated Mode for both retorts. The ability to maintain continuous heater operations for the Semi-Works Indirect Heated Mode was shown by the ability to operate without coke deposition in the heater, hot gas system, or on the inlet tube header. The ability to remove all of the oil mist was responsible for the clean inlet tube header and moisture control of the gas stream controlled the coke deposition.

The Pilot and Semi-Works external heaters were not the best design for this service. They were obtained

as a compromise as heaters designed for this type of service could not be delivered in time for use in the program as scheduled. The Pilot Plant Indirect Heated Mode never reached an operable condition before failure of these heaters occurred. The Semi-Works heaters accounted for a major amount of lost time during these operations.

The maximum temperatures for processing were limited by the heater capability on both the Pilot and Semi-Works plants. The Pilot retort was not able to operate above 1300°F. The Semi-Works heaters achieved a 1300°F gas inlet temperature at the distributor and approximately 1400°F at the heater discharge. The Semi-Works heaters were limited by maximum firebox temperatures and recycle flue gas temperatures based on the manufacturer's recommendations.

Problems with the Semi-Works external heaters involved breaks in the tubes, tube sheets, and expansion bellows which allowed process gas to escape into the firebox section. Heater problems also limited the operations in the Indirect Heated Mode to a single heater operation. The proposed two level hot gas entry as performed for Direct Heated Mode operations was not achieved in the Indirect Heated Mode.

The Pilot Plant external heaters failed when the Inconel fins deteriorated and prevented gas flow through the heater. The fins appeared to have carbonized and melted during the operation.

Very few operational problems occurred with the air-gas distributors, except during periods of oil mist carry-over from the recovery system. During early Semi-Works runs, when some oil mist may have been recycled, a problem of coke buildup on the orifice openings restricted the gas flow. Later Semi-Works operations, such as the 25-day Direct Heated Mode demonstration run, showed no evidence of a distributor coking problem.

The process air supply for each retort is a multi-stage centrifugal blower similar to the recycle blower. The discharge of the Semi-Works air blower is partially vented to atmosphere to prevent pressure surging. To limit excessive capacity and prevent pressure surging, a restricting orifice is used on the suction of the Pilot Plant air blower. Both machines are equipped with dry suction filters to remove dust. There were no operational problems with either process air system.

Gas and air measurement is made using a sharp edge orifice plate meeting the design standards of the American Gas Association. Orifice plates cause a permanent pressure loss but are highly reliable, easy to maintain, and known to have an accuracy of $\pm$ 2% when properly installed.

Gas and air flows are recorded continuously on miniature circular charts. The differential pressure leads are connected to manometers for better readability. Flow rates were calculated using the procedures in "Principles

and Practice of Flow Meter Engineering" by Spink (Foxboro Co.). The computer program listing is Table 7-1 in Section 7.1.

A low rate air purge is used through all gas differential pressure and static pressure lines to free them of oil. This air purge or bubbler increases the reliability of the measurements.

All gas and air orifice taps are equipped with line drains to remove trapped liquid. Periodic checking or draining of these drain lines is done during operations. The drain valves are maintained in a closed position except during periods of liquid drainage. All accumulated oil or water is then piped to the rundown tanks for inclusion in product oil for measurement.

Some locations of product gas loss have been previously described (top and bottom rotary seals); other minor losses were identified. These losses occurred sometimes at the blower seals, the hydralic cylinder seal boxes, the distributor packing glands, during liquid drainage, and through other minor leaks within the system. In the Indirect Heated Mode, internal leakage into the heaters was known to be a major loss during some operations. The largest unmeasured gas loss was the recycle blower shaft seal. This was essentially corrected prior to Semi-Works Run No. SW-27 when an enclosure and a return line to the suction of the blower was installed. None of the minor gas losses have been measured or accounted for in the reported data except

for heater gas loss when identified.

The pressure at the top of the retort is regulated by a pressure controller which positions the product gas control valve. This procedure provides very small pressure fluctuations. During Indirect Heated Mode operations, a line containing a small control valve was used because of the reduction in product gas quantity of approximately 10 to 1 compared to the Direct Heated Mode. Only during periods of extreme upset or excessive gas loss did problems occur in this control technique.

5.3.3 LIQUIDS

The oil mist particles produced in oil shale retorting processes are very small. Average particle diameter is only 3 microns. It is carried through the shale bed in the gas stream without appreciable impingement upon the shale particles. Because of the small particle size, specialized collection equipment is required. The equipment used for the collection of such minute particles in a gas stream should also meet many other requirements which are as follows:

1. The collection must be continuous.
2. The equipment must be capable of handling the liquid oil product.
3. The collector must have a very low pressure drop.
4. It must withstand the temperatures and physical and chemical conditions of the gas and oil.

5. The collector should be inexpensive and easy to construct.
6. The collection efficiency should be high.
7. The unit should be self-cleaning and suited for long continuous service with a minimum of operator and maintenance attention.
8. It should have low power requirements.
9. The collector should minimize contamination or dilution of product oil.

Numerous collection devices have been tried during the experimental work on other similar retorting processes. Results of previous work showed the electrostatic precipitator to be the most suitable single piece of apparatus for this service.

The initial oil recovery system for the Paraho retort was made using an electrostatic precipitator as the single collection device. During the testing of the Indirect Heated Mode in the Pilot Plant Run PP-11 and the testing of high mass rates on the Semi-Works Runs SW-8 and 9, the ESP collection system efficiency decreased. Coalescers (Drawings 10 and 11) were designed and installed, to improve oil recovery. Their collection principle is to coalesce the oil mist particles with a cool oil spray system and then to remove the larger particles by impingement. By controlling the degree of cooling and the quantity of oil spray used, a control of gas temperature is also achieved. Mist removal in the coalescer is approximately 50% under most

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operating conditions, thus lowering the input loading of the elecstrostatic precipitator by 50%. The system has minimal pressure drop. A correction in the gas entry to the Semi-Works electrostatic precipitator during the installation of the coalescer also helped overall recoveries.

The installation of the coalescer system also stabilized the electrostatic precipitator operation at all times on both the Pilot and Semi-Works retorts, resulting in fewer problems of mist recovery. The total system achieves the nine requirements previously listed, and in addition, provides a method of temperature control for the gas stream.

An additional change was made to the coalescer prior to the final Indirect Heated Mode operation on the Semi-Works retort starting with Semi-Works Run SW-21. The baffled section of the coalescer was converted to an oil-gas contactor using 2-inch Pall rings. This was done to to provide better gas contact with cool oil. This addition was made within the gas passage area of the impingement section.

Experiences during the Indirect Heated Mode operations, show no increase in collection efficiency from the packing section addition. However, cooling of the gas stream was easily accomplished. Temperature control was always maintained. Periods of sediment carryover existed but no problem in plugging of the coalescer impingement or packing sections was noted. Additional pressure drop resulted.

The oil, after collection, is piped directly to rundown tanks for measurement and sampling. Initially the oil drained by gravity. The Pilot Plant operated satisfactorily with the gravity drain system. Minor problems occurred in some earlier runs in the Semi-Works retort with sludge blocking the drain lines in the gravity overflow system. During Run SW-12, a change in the system allowed the oil to discharge to tankage through a bleed line from the pump supplying spray oil. After the installation of the coalescer, sediment is removed with the coalescer oil, reducing problems in the electrostatic precipitator and recycle gas pipes.

All oil handling systems require heat tracing and insulation in order to maintain temperatures above the pour point of the oil. During shutdown conditions, this is also required to prevent freezing during cold weather.

The oil rundown and storage tanks systems are shown in Drawing 6. Steam-heated, insulated tanks are used. The only precautions taken to retain the volatile fractions within the oil is to maintain a minimum temperature on the oil during storage.

Both sediment and water separate readily in storage tanks. The water condensed in the bottom gas cooler used in the Indirect heated Mode operations is separately gaged and sampled.

5.3.4 RETORT WEAR RATES

An inspection of the Pilot and Semi-Works retorts and associated equipment was made to determine the extent of wear during the operating period from mid - 1974 to April 1976. The following is an outline of the equipment examined and explanatory remarks.

Pilot and Semi-Works Retort

Solids

- Raw Shale Screen Feeder
- Raw Shale Weighbelt
- Raw Shale Rotary Seals
- Raw Shale Level Control
- Raw Shale Distributor
- Retort Lining
- Discharge Mechanism
  - Moving mechanism including pusher, spacer bars, clevis etc.
  - Fixed components including inverted V's, retarder plates, etc.
  - Hydraulic cylinders
  - Hydraulic circuitry
  - Volume controls
- Retorted Shale Discharge Cone
- Retorted Shale Rotary Seals
- Retorted Shale Weighbelt

Gases

Off-gas Collectors (Semi-Works)

Top Distributors

Middle Distributors

Bottom Distributors

Instruments

Retort Thermocouples

Retort Pressure Taps

SOLIDS

There has been no measurable wear to the shale handling equipment with minor exceptions as follows:

1. The screen on the Semi-Works screen feeder developed holes where the shale entered the screen from the surge bin. Both the Semi-Works and Pilot Plant screens developed fatigue cracks from vibrating motion. A plate was installed to relieve the wear on the screen inlet and the cracks were welded. A stronger screen is recommended.
2. The retorted shale weighbelt on the Semi-Works retort was unable to withstand the retorted shale discharge temperatures of the preliminary operations in the Indirect Heated Mode. Improved operating conditions and better thermal efficiency in later operations resulted in lower discharge temperatures of the retorted shale. The belt wear was reduced to minimal.

3. The lining wear in both retorts was negligible and not detectable until after operation in the Indirect Heated Mode in the Semi-Works retort. In the area adjacent to the hot gas entry, the glaze from the bricks is gone and a rough, porous surface remains. Mortar between bricks in the same area has been eroded up to 3/4 inch.

4. The hydraulic cylinders required appreciable maintenance of rod seals in the early operating periods. An improved seal was used and an extension support was put on the cylinders and operating time extended before maintenance was required.

   After cast iron ring seals were installed and alignment was checked, the cylinders did not require further maintenance.

5. The retorted shale rotary seals showed considerable wear in the initial units that were used. An improved design was developed by the manufacturer and the new seals were installed in August, 1975. Wear effect was decreased in all parts of the seals. The wear rate is shown in the following table:

TABLE 5-2
ROTARY SEAL WEAR RATES

Date	Tonnage	Wear Rates, Inches: End	Radial	Average Per 1000 Tons
Aug. 1975	0	0.017	0.017	---
Dec. 1975	5000	0.026	0.022	.0014
Apr. 1976	10000	0.040	0.044	.0036

Gases

The service of the distributors has been good. The only exception to good performance has been some cracking of the welds along the top distributor between the water jacket and the stainless steel distributor pipe. There is no evidence to indicate the cracking occurred from other than fabrication defects in the shop welding.

Instruments

The retort thermocouple-pressure probe gave very rapid response to variations in retort operation but structurally needs improvement as several of the extended couples broke off. The pressure taps located in the retorting zone also would become plugged. The main pipe of the probe showed no unusual wear.

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5.4 AUXILIARY SYSTEMS

The cooling water, fuel oil, plant air, propane and shale oil storage facilities are shown on Drawing 6. The steam, dust collection and thermal oxidizer systems are shown on Drawing 7. Except for the crude shale oil gaging tanks and dust collectors, the systems serve both the Pilot and Semi-Works Plants.

The cooling water system consists of a primary receiver and make-up tank, the interconnecting piping, the necessary temperature and regulating controls, the circulating pumps and the air-cooled heat exchanger. The usage of cooling water is:

Direct Mode Operation	Indirect Mode Operations
Spray Oil Cooler (SW & PP)	Bottom Gas Cooler (SW)
Air-Gas Distributors (SW&PP)	Wash Oil Cooler (SW)
	Spray Oil Cooler (SW & PP)

The fuel oil is stored in four 500-barrel tanks and the fuel oil pumps circulate the oil through the plant area and back to the tanks. Fuel oil is used for:

Process Steam Boilers

Semi-Works Plant Heater

Plant Heating Steam Boiler

Thermal Oxidizer

The plant air system utilizes a new compressor and two old compressors that were located in the old boiler house. The new compressor provides instrument and plant air to the control room for distribution. The two old compressors supply air to the bag filters that are air pulsation type. The two systems are valved and piped to spare each other primarily to insure the availability of air for the instruments.

There is no natural gas available at the Anvil Points site and therefore propane is used. The propane system consists of two 1200-gallon tanks, piping and instrumentation. To insure vapor phase propane in the cold winter months for start-up purposes, an additional 500-gallon tank and vaporizer are located in the retort area. Propane is supplied to:

- Pilot Plant
  - Direct Heated Mode Start-up
  - Heater Burners
  - Heater Pilots
- Semi-Works Plant
  - Direct Heated Mode Start-up
  - Heater Pilots
- Thermal Oxidizer Pilots
- Laboratory

The tankage for shale oil storage at Anvil Points has a capacity of about 20,000 barrels. However, only about 17,000 barrels can be stored in usable tanks. Drawing 6 for shale oil storage primarily shows the rundown and gaging tanks. The Pilot Plant uses tanks 525 and 526. The Semi-Works Plant uses tanks 519 through 524. All of these tanks are steam-heated and insulated. The system has the capability of circulating the oil from a tank, through a pump while the tank is being agitated prior to the oil sample being taken.

The plant steam is produced by two package boilers. This system is tied to the plant steam heating system as a spare supply in case of failure. The plant steam is used for:

Thermal Oxidizer Burner Fuel Atomization
Propane Vaporization
Crude Shale Oil Tank Heating
Rotary Seal Purge Gas
Crude Shale Oil Line Tracing
Control Room Heating
Shale Preparation Building Heating

Dust collection equipment was used to comply with regulations for particulate emissions. The State of Colorado Health Department in cooperation with the Mining Enforcement and Safety Administration (MESA) and the Colorado Bureau of Mines (CBOM) were the regulatory agencies for Anvil Points.

The necessary permits were received to construct and a final inspection by the Air Pollution Control Division, while the shale preparation areas and both Pilot and Semi-Works Plants were operating, resulted in a permanent permit to operate. The Paraho Project was not cited for a violation during the program.

The dust collectors are bag filter type. The particulate material from the retort plant collectors is transported to the retorted shale area. The particulates from the shale preparation areas are transported to the same canyon but separate from the retorted shale.

Since there was no effective way to utilize the product gas, the thermal oxidizer is used to burn the product gas from the Pilot and Semi-Works Direct and Indirect Heated Mode operations before emission to the atmosphere. A checkerbrick system was installed in the burner discharge area of the combustion chamber to improve the overall efficiency of combustion. Because of the smaller quantities of product gas to be burned from the Pilot retort, fuel oil is used as an auxiliary fuel. During stable periods of the Semi-Works retort operations, the low BTU gas from the Direct Heated Mode and the high BTU gas from the Indirect Heated Mode do not require auxiliary fuel oil to maintain combustion and complete oxidiation takes place before emission. The pilot is maintained for safety purposes.

6. STARTUP PROCEDURES

6. STARTUP PROCEDURES

6.1 DIRECT HEATED MODE STARTUP PROCEDURES

Many startup procedures have been previously used for vertical kiln gravity flow retorts, but all have presented problems or were not adaptable to larger size units. The development of a new procedure, based on a concept that could be adapted to commercial size retorts, was initiated at the beginning of Paraho operations. Success was achieved on Pilot Plant Run PP-1 and refinements continued through most of the Direct Heated Mode operation on both retorts.

This startup procedure is based on the principle of a controlled combustion of gaseous fuel within the bed to preheat the shale particles to ignition temperature. Propane has been used as the fuel for the ignition step. When proper operating temperatures are achieved within the bed, the propane fuel is removed and normal process flows established.

Minor variations to the original Pilot Plant procedures were required for the Semi-Works retort to prevent the combustion of product gases above the open bed. Changing the air gas ratios during the propane firing controlled this and led to the use of a full shale bed for the startup. This provides some preheating of the shale in the upper sections of the bed above the combustion zone making it less susceptible to process upsets during the

early stages. The direct combustion within the bed provides a rapid startup reaching shale combustion temperatures within 18 minutes of the propane ignition.

This startup procedure was primarily developed in the Pilot Plant but the technique has proven safe and reliable for both retorts and can easily be adapted to commercial size. The startup is rapid, reaching normal operating conditions within nine hours. A minimum of specialty equipment is required such as a gaseous fuel source and control system and an air-fuel mixer in the top distributor air supply line. Final refinement includes a method of exhausting all products of combustion during the propane firing through the product gas thermal oxidizer. This technique provides pollution control throughout the operation.

A quick opening valve is required for the gaseous fuel supply. Flow rates must be achieved as rapidly as possible to prevent the dangers of explosive mixtures of air and gas being used. Individual flow rates are pre-set followed by purging, and then the ignition sequence is started. A safety shut off is also incorporated in this valve to provide a shutdown of the system in case of an air blower or power failure. The details of this installation are shown in Drawings 3 and 4.

The startup procedure begins with a full bed of raw shale. A non-compacted bed is assured by operating the grate and completely circulating shale through the retort

while maintaining a level in the retort level hopper. One complete change of shale eliminates compaction due to the initial filling of the retort. No other special shale preparation or other materials are required. Flow rates are set to provide a rich mixture of propane in air at the top distributor with the additional air requirements for combustion being added at the mid distributor. To ignite the fuel mixture, igniters are inserted into the bed through special openings. Signal flares have proven to be well suited for this purpose as they can be dropped on the surface of the bed and buried in the shale by starting shale flow through the retort.

After the igniters have been inserted, propane is added to the air, supplying a combustible mixture that will burn within the shale bed when upward gas velocity is less than the flame velocity. Using a series of air and gas changes, the internal combustion can be controlled to preheat the shale bed and bring the shale to ignition temperatures at the normal combustion zone level.

As the shale reaches retorting and combustion temperatures, the propane supply is cut off and the recycle system started. A gradual buildup of air and gas additions is used to spread the combustion zone across the complete retort cross-section. This is a step-wise procedure. As the temperature profiles are established, both vertically and horizontally, the shale rate is increased until full

operating conditions are achieved.

The startup time sequence can be varied greatly following the propane ignition since the process is operable over wide variations of air, gas, and shale rates. The period from propane ignition to normal operating conditions, using two level air input at 400 $lbs/hr/ft^2$ has been achieved in nine hours.

6.2 INDIRECT HEATED MODE STARTUP PROCEDURE

A reliable startup procedure for the Indirect Heated Mode was achieved using a technique of preheating the retort filled with a non-kerogen bearing rock. This provides a method of establishing a vertical temperature profile before feeding shale to the retort. This procedure enhances the mist formation in the preheating zone. The procedure developed uses an initial retort loading of an inert material such as crushed and screened limestone or gravel. The system is then purged of oxygen using an inert gas.

Direct Heated Mode product gas from the Pilot Plant was used for purging because of its availability during this program. Gas circulation is started to purge the retort, the recirculation piping and oil recovery equipment. The heaters and oil recovery equipment are started when the oxygen content of the circulating gas stream drops below 2%. A continuous purge of inert gas is maintained to prevent air in-leakage during the preheating periods.

Low velocity stone movement is maintained during the retort preheating operation to establish the vertical temperature profile in both the top and lower section of the retort. This movement also prevents thermal expansion from locking the stone particles within the bed. During the preheating period, the stone rate is adjusted to maintain a desired off-gas temperature.

A slow rate of gas temperature increase through the heater must be maintained to prevent thermal distortion. The temperature level is raised within the bed of inert stone until sufficient temperature is achieved to provide retorting. When this temperature level is reached, the inert rock feed is replaced with raw shale. Gas flows and temperatures are adjusted as required to bring the shale feed changeover into normal operating conditions as smoothly and quickly as possible.

Purging with inert gas is continued until adequate product gas is being produced from the retorting of shale to maintain adequate pressure control. The startup provides a rapid method of achieving a normal Indirect Heated Mode operation with a minimum of process upset. The oil recovery equipment is fully commissioned, thus providing a clean gas to the heater throughout the startup. Full operating conditions can be achieved in about 12 hours.

7. COMPUTER PROCESSING

7 COMPUTER DATA PROCESSING

7.1 INTRODUCTION

The computing equipment used was a Hewlett-Packard 9830A general purpose programmable calculator. The program language is called BASIC. Input is by typewriter keyboard and output by the 9866A line printer. There is a built-in tape drive for large capacity storage. The read/write memory size is 3808 16-bit words.

Programs are written and edited at the keyboard and are stored on tape casettes. Data is stored in test data files on tape cassettes and called from the keyboard.

Manufacturer's software tapes were used for polynomial regression and analysis of variance.

PROGRAMS USED FOR GAS CALCULATIONS

A gas calculation program was written to calculate specific gravity, molecular weight, and gross and net heating value* based on the composition of the retort gas. The specific gravity determined in this program is then input to the flow calculations program along with orifice differential pressure and flowing temperature and pressure to calculate bottom, mid, top, and product gas flow rates (SCFM). The air flows, (Bottom, mid, and top), are also calculated. These values along with other input data are stored on computer data tapes. This information can then be loaded into common memory and run through the material and heat balance programs.

The reference for the flow calculation program is "Principles and Practice of Flow Meter Engineering by L. K. Spink (1967) Foxboro." Table 7-1 is a program listing.

NOTES APPLICABLE TO DIRECT AND INDIRECT MODE MATERIAL AND HEAT BALANCES

Data input are of two different types. The first is raw data either recorded at the unit (e.g. off gas temperature), or determined at the laboratory. The other is calculated from other peripheral computer programs, (e.g. gas flows from manometer readings).

WATER BALANCE

A. Laboratory tests of raw shale are performed and

*Gas Engineering Handbook, American Gas Assoc., Inc.

reported on an undried basis. The program input data then is internally adjusted using a moisture determination on an undried sample. In the Indirect Heated Mode water balance, the laboratory moisture is subtracted from F.A. water to obtain the "true" F.A. water. This was not done in the Direct Heated Mode water balance.

B. It is assumed that the retorted shale is totally water-free. This was confirmed by several specially handled retorted shale samples.

C. Water balances will reflect the continued improvement in accounting for water contents throughout the program. Major problems were associated with the sampling and analysis of raw shale feed and product gas and the accounting for miscellaneous condensate drainage.

ORGANIC NITROGEN

Analysis techniques for ammonia content in the product gas streams and condensed water were only developed during the final Direct Heated Mode runs. An accounting for this component was therefore not included in the Direct Heated Mode computer program, which results in an incomplete organic nitrogen balance.

The Indirect Heated Mode computer program does account for the ammonia contents and a complete organic nitrogen balance is therefore obtained.

CARBONATE DECOMPOSITION (BTU/T)

Partitioning of mineral carbon dioxide is based on information from USBM Bulletin 635. Dolomite content was reported as 30% of mineral carbonate. If carbonate decomposition, measured as Lb-mol CO_2/ton, is less than or equal to 2.5, this value is multiplied by 58,835 BTU/# mol as the heat of decomposition of $MgCO_3$. The program treats carbonate decomposition in excess of 2.5 #/mol CO_2/ton as liberated from the decomposition of $CaCO_3$, whose heat of decomposition is 75,096 BTU/lb.-mol.

SHALE MOISTURE QUANTITIES

A. The Tylab moisture is the wt% H_2O on the uncrushed shale.

B. The lab moisture is the wt% H_2O on the crushed lab sample.

HEAT OF PYROLYSIS

The heat of pyrolysis used is 32 BTU/# for 30 GPT shale. In the work reported in U.S.B.M. RI-7482, "Heat Contents of Some Green River Oil Shales," endothermic reactions at retorting temperatures of 17 BTU/# for 15 gal/ton shale and 35 BTU/# for 32.4 gal/ton shale were reported.

SKIN HEAT LOSSES

The heat loss from the retort shell was measured under various ambient and operating conditions and compared

to calculated values. From these losses, based on average operating and ambient conditions, a constant heat loss value of 10,000 BTU/T or about 2% of the heat input, was used throughout the heat balance calculations.

GAS ENTHALPY

The gas component enthalpies used in the heat balance were obtained from the "Circular of the National Bureau of Standards C461," as part of the work of the American Petroleum Institute Research Project 44. Polynomial regression was used to convert the tabular data to equation form.

7.2 DIRECT HEATED MODE

A flow chart of the Direct Heated Mode material balance is presented in Figure 7-1. The program listing for Part 1 is Table 7-2 and for Part 2 is Table 7-3.

MATERIAL BALANCES - Part 1, Preliminary Calculations

The input data from the data tape is converted by preliminary calculations in Part 1 and stored in a Calculated Data Array shown in Table 7-4. Some of these calculations are explained in Table 7-5.

The combustion reactions considered are formation of CO_2, CO, and water vapor. From a material balance of the Fischer Assay, the production of CO_2 and CO by pyrolysis is calculated. Mineral carbon dioxide is also calculated. Thus, net carbon oxides from combustion are determined. The oxygen

input with air is calculated and the oxygen by difference is used to calculate the combustion water formed.

MATERIAL BALANCES - Part 2

The partial balances and the overall weight balance are discussed in Table 7-6. Execution of this Part 2 prints the complete material balance which excludes recycle gas streams.

HEAT BALANCE

The flow chart of the heat balance for the Direct Heated Mode is presented as Figure 7-3. The program listing in Table 7-7. The program uses preliminary calculations performed in the material balance and stored in the calculated data array.

The steps of the calculation are shown in Table 7-8. The bases of calculations are believed to be self-explanatory along with the preceding text captioned, "Notes Applicable to Direct and Indirect Mode Material and Heat Balances" in Section 7.1.

Figure 7-2 shows the heat balance boundary and identifies the streams tabulated in the print out. Table 7-9 is a print out of input data, the material balance, and the heat balance for Direct Heated Mode Run SW-20, combined Test "A".

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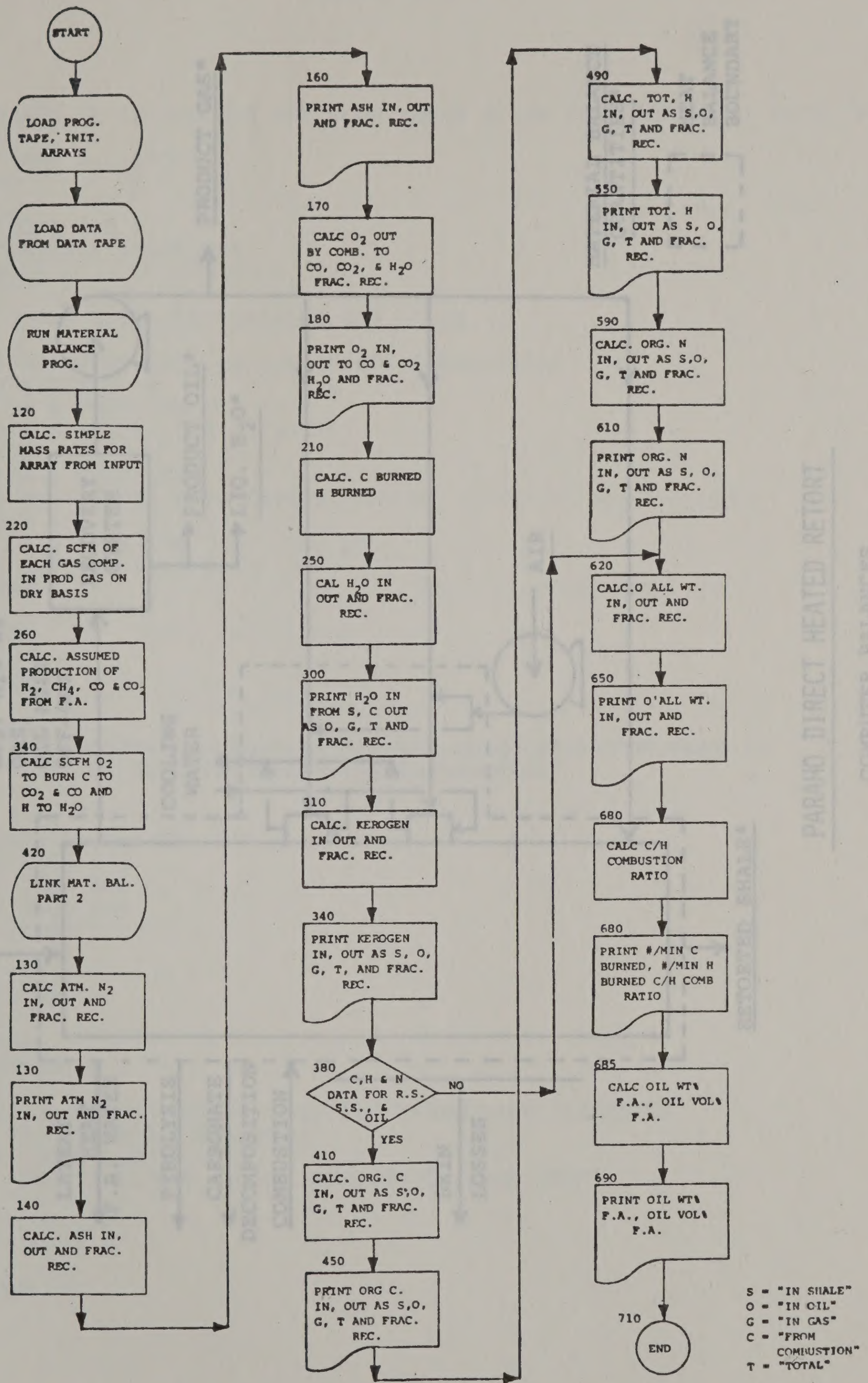
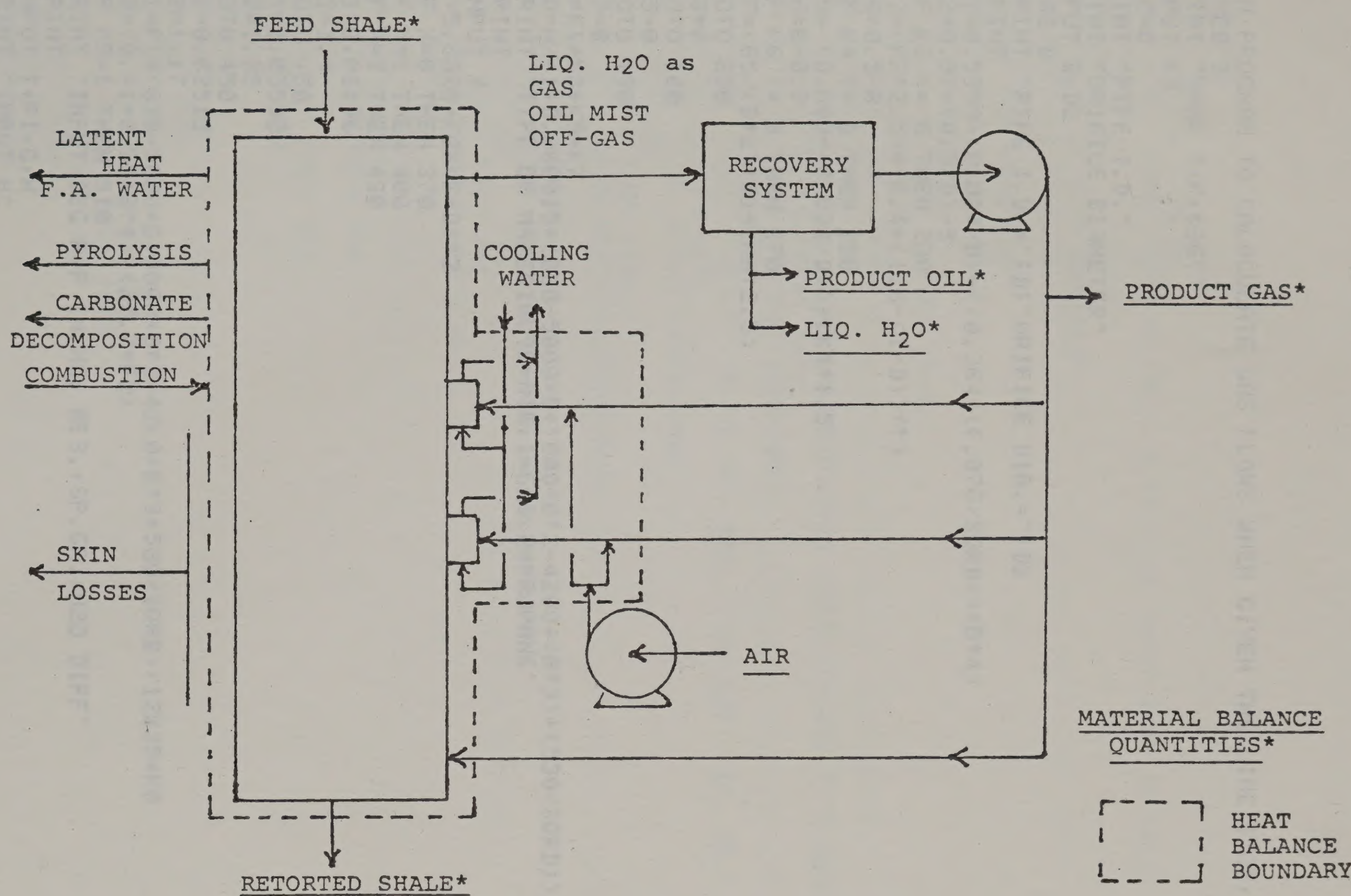
DIRECT HEATED MATERIAL BALANCE COMPUTER FLOW CHART

Figure 7-1





PARAHO DIRECT HEATED RETORT

COMPUTER BALANCES

FIGURE 7.2

GAS FLOW CALCULATION PROGRAM

TABLE 7-1

```
10 REM PROGRAM TO CALACULATE GAS FLOWS WHEN GIVEN THE LINE SIZE, ORIF. D.
20 FIXED 3
30 PRINT "SAME T,P,&SG?"
40 INPUT K9
50 R=Z=0
60 PRINT "PIPE I.D."
70 PRINT "ORIFICE DIAMETER"
80 INPUT D,D2
90 B=D2/D
100 PRINT "PIPE I.D.=";D;"ORIFICE DIA.=";D2
110 PRINT
120 K1=0.5993+(0.007/D)+((0.364+(0.076/SQRD))*B↑4)
130 K2=0.07+(0.5/D)-B
140 IF K2 <= 0 THEN 230
150 K3=(K2↑2.5)*(0.4*(1.6-(1/D))↑5)
160 K4=0.5-B
170 IF K4 <= 0 THEN 250
180 K5=-(0.009+(0.034/D))*(K4↑1.5)
190 K6=B-0.7
200 IF K6 <= 0 THEN 270
210 K7=(65/(D↑2)+3)*(K6↑2.5)
220 GOTO 280
230 K3=0
240 GOTO 160
250 K5=0
260 GOTO 190
270 K7=0
280 N=K1+K3+K5+K7
290 K0=N/(1+0.000015*(830-5000*B+9000*B↑2-4200*(B↑3)+(530/SQRD)))
300 PRINT "TYPE OF MATERIAL?0=AIR,1=GAS,2=PROPANE"
310 PRINT
320 INPUT X
330 F=5.6328*K0*(B*D)↑2
340 IF X=0 THEN 370
350 IF X=1 THEN 400
360 IF X=2 THEN 430
370 F1=0.06196
380 F2=1.4
390 GOTO 450
400 F1=0.05592
410 F2=1.35
420 GOTO 450
430 F1=0.02513
440 F2=1.17
450 C1=F1*(830-5000*B+9000*B↑2-4200*B↑3+530/SQRD)/12835*K0
460 C2=(0.41+0.35*B↑4)/(27.7*F2)
470 IF K9=1 THEN 510
480 PRINT "INPUT DEG F,P IN.HG. ABS.,SP.GR.,H2O DIFF"
490 PRINT
500 INPUT T,P1,G,H
510 PRINT "INPUT H"
520 INPUT H
530 H=H*1.07
```

TABLE 7-1 (Contd)

```
540 R=T
550 Z=P1
560 P=P1*14.7/29.92
570 PRINT "INPUT SCFM TO CALC. DIFF., OR INPUT ZERO TO CALC. SCFM"
580 PRINT
590 INPUT S
600 PRINT S;"SCFM DESIRED"
610 P=P1*14.7/29.92
620 D=0
630 IF S>0 THEN 860
640 IF H>0 THEN 660
650 H=0.000001
660 F2=1+C1*SQR((T+450)/(H*P))
670 F3=1-(C2*H/P)
680 F4=SQR(520/(460+T))
690 F5=SQR(1/G)
700 F6=SQR(1+((P-11.5)*9.16*10↑5*10↑(1.188*G))/(460+T)↑3.825)
710 F7=0.9988+(0.004*T/228)
720 K=F*F2*F3*F4*F5*F6*F7*SQR(H*P)
730 IF S>0 THEN 860
740 PRINT "SCFM","DEG.F","P IN. HG. ABS.","IN.H2O","SP. GR."
750 PRINT K,T,P1,H,G
751 PRINT "STD. DEV.? 1=YES,0=NO"
752 INPUT Z9
753 IF Z9=1 THEN 1250
760 PRINT "SAME ORIFICE?1=YES,0=NO"
770 INPUT K2
780 IF K2=0 THEN 10
790 PRINT "SAME TEMP PRESS AND SG?1=YES,0=NO"
800 INPUT K3
810 IF K3=0 THEN 480
820 PRINT "INPUT H20 DIFF"
830 INPUT H
840 GOTO 530
850 GOTO 1060
860 IF D=0 THEN 900
870 D=D+1
880 IF D>3 THEN 950
890 GOTO 930
900 H=10
910 D=D+1
920 GOTO 660
930 J=K/SQRH
940 H=S↑2/J↑2
950 IF S>K+0.1 THEN 990
960 IF S<K-0.1 THEN 1010
970 IF S=K THEN 1030
980 GOTO 1030
990 H=H+0.01
1000 GOTO 660
1010 H=H-0.01
1020 GOTO 660
```

TABLE 7-1 (Contd)

```
1025 H=H/1.07
1030 PRINT "SCFM","IN.H2O","DEG.F","P IN. HG. ABS.","SP. GR."
1040 PRINT K,H,T,P1,G
1050 IF X=10 THEN 1350
1059 X1=1
1060 GOTO 760
1070 PRINT
1080 INPUT X
1090 IF X=0 THEN 1210
1100 PRINT "INPUT TEMP. INCREMENT AND P IN. HG. INCREMENT"
1110 PRINT
1120 INPUT A,B
1130 PRINT A,B
1140 PRINT "NUMBER OF TEMP. AND PRESS. INCREMENTS DESIRED? INPUT N1 & N2"
1150 PRINT
1160 INPUT N1,N2
1170 PRINT N1,N2
1180 PRINT
1190 GOTO 1360
1200 GOTO 610
1210 PRINT "DO YOU WANT THE STD. IEV. OF THE FLOW (SCFM)? 1=YES, 0=NO"
1220 PRINT
1230 INPUT X
1240 IF X=0 THEN 1060
1250 PRINT "WHAT IS THE STD. DEV. OF THE MANOMETER SETTING?"
1260 INPUT H1
1270 PRINT H1
1280 K1=K*H1/H/2*1.07
1290 PRINT "SCFM=";K;"+OR-";K1
1300 GOTO 760
1310 PRINT
1320 INPUT X
1330 PRINT
1340 IF X=0 THEN 1420
1350 IF X=1 THEN 60
1360 T=T+A
1370 IF T<(R+N1*A) THEN 610
1380 T=R
1390 P1=P1+B
1400 IF P1<(Z+N2*B) THEN 610
1410 GOTO 1300
1420 STANDARD
1425 PRINT "INPUT S"
1426 GOTO 590
1430 END
```

DIRECT HEATED MODE MATERIAL BALANCE

TABLE 7-2

```
10 COM H$[6],F$[9],Y$[8],R$[5],A$[4],T$[6],G$[14],P$[15],C$[10,10]
20 K=0
30 C[10,2]=0
40 FOR I=1 TO 10
50 C[10,2]=C[10,2]+G[I]
60 NEXT I
70 C[10,2]=C[10,2]+G[13]
80 C[10,1]=(C[10,2]+G[12])/C[10,2]/100
90 FOR I=1 TO 10
100 C[8,I]=G[I]*C[10,1]
110 NEXT I
120 C[1,1]=F[1]*2000/60
130 C[1,3]=Y[1]*2000/60
140 C[7,2]=Y[7]/60*8.33
145 C[6,9]=C[1,1]*100/(100-F[9])
150 C[1,5]=0.79*(A[1]+A[2]+A[3])
160 C[3,7]=C[6,9]*F[5]/100+(C[1,1]*F[2])/(100-F[2])
162 C[1,6]=R[4]*G[2]/100
164 C[3,8]=R[4]*G[12]/100
180 C[3,9]=C[3,8]/(C[3,8]+C[1,6]/C[8,2])
190 C[10,3]=R[4]
195 C[1,6]=C[10,3]*G[2]/100
200 C[7,1]=Y[6]/60*8.33*141.5/(Y[8]+131.5)
220 FOR I=1 TO 10
230 C[9,I]=C[8,I]*C[1,6]/C[8,2]
240 NEXT I
250 C[2,1]=0.21*(A[1]+A[2]+A[3])
260 K=C[6,9]/2000*F[3]/29.3
270 C[10,6]=123*K
280 C[10,7]=26*K
290 C[10,8]=107*K
300 C[10,9]=137*K
310 C[10,10]=52*K
320 C[10,4]=C[9,6]-379/44/100*(C[6,9]*F[7]-C[1,3]*Y[3])
330 C[10,4]=C[10,4]-C[10,9]
340 C[2,5]=C[9,4]/2-C[10,7]/2
350 C[2,2]=C[10,4]+C[2,5]
360 C[4,1]=C[9,1]/C[6,9]*2000
370 C[6,10]=C[2,1]-C[2,2]-C[9,3]
420 LINK 1
430 END
```

DIRECT HEATED MODE MATERIAL BALANCE PART 2

TABLE 7-3

```
10 COM HS[6],FS[9],YS[8],RS[5],AS[4],TS[6],GS[14],PS[15],CS[10,10]
20 PRINT "MAT. BAL. PROG. LOADED. COPYRIGHT 1975,PARAHO DEV.CORP"
30 FORMAT F8.2,5X,F8.2,12X,F15.3
40 FORMAT 26X,F8.2,X,F3.0
50 PRINT "NOW RUN70"
60 STOP
70 C[1,2]=A[4]
80 C[2,10]=C[6,10]
100 C[1,4]=C[3,8]+C[9,2]/C[8,2]
110 PRINT "BALANCES","IN","OUT","UNITS","FR.REC."
120 PRINT
130 WRITE (15,30)"ATM. NITROGEN",C[1,5],C[1,6],"SCFM ",C[1,6]/C[1,5]
140 C[1,7]=C[6,9]*F[3]/100
150 C[1,8]=C[1,3]*Y[4]/100
160 WRITE (15,30)"ASH             ",C[1,7],C[1,8],"#/MIN",C[1,8]/C[1,7]
170 C[6,6]=C[2,2]+C[2,10]
180 WRITE (15,30)"OXYGEN          ",C[2,1],C[6,6],"SCFM ",C[6,6]/C[2,1]
190 WRITE (15,40)C[2,10],"TO H2O"
200 WRITE (15,40)C[2,2],"TO CO&CO2"
210 C[2,6]=C[10,4]*12/379+(C[2,2]-C[10,4])*24/379
220 C[2,7]=C[2,10]*4/379
230 C[1,9]=C[3,7]+C[2,10]*36/379
240 C[1,10]=C[7,2]+C[3,8]*18/379
250 WRITE (15,30)"WATER           ",C[1,9],C[1,10],"#/MIN",C[1,10]/C[1,9]
260 FORMAT 13X,F8.2,X,"S",3X,F8.2,X,"L"
270 WRITE (15,260)C[3,7],C[7,2]
280 FORMAT 13X,F8.2,X,"C",3X,F8.2,X,"V"
290 WRITE (15,280)C[2,7]*36/4-C[4,1]*C[6,9]/2000*18/379,C[3,8]*18/379
300 C[2,8]=(100-F[8]-F[7]-F[5])*C[6,9]/100
310 C[2,9]=C[9,1]*2+C[9,5]*16+C[9,7]*28+C[9,8]*30+C[9,9]*43+C[9,10]*57
315 C[2,9]=C[2,9]/379
320 C[2,9]=C[2,9]+C[1,3]*(100-Y[4]-Y[3])/100+C[7,1]
330 C[2,9]=C[2,9]+C[2,7]+C[1,4]/379*G[13]*1.44+(C[9,6]+C[9,4])*12/379
332 C[2,9]=C[2,9]-(F[7]*C[6,9]-Y[3]*C[1,3])/100*12/44
340 WRITE (15,30)"KEROGEN         ",C[2,8],C[2,9],"#/MIN",C[2,9]/C[2,8]
350 WRITE (15,40)C[1,3]*(100-Y[4]-Y[3])/100,"S"
360 WRITE (15,40)C[7,1],"O"
370 WRITE (15,40)C[2,9]-(C[1,3]*(100-Y[4]-Y[3])/100)-C[7,1],"G"
380 IF P[2]=0 THEN 620
390 IF P[5]=0 THEN 620
400 IF P[8]=0 THEN 620
410 C[6,7]=C[6,9]*(P[2]-F[7]*12/44)/100
420 C[6,8]=(C[1,3]*(P[5]-Y[3]*12/44)+C[7,1]*P[8])/100
430 C[6,8]=C[6,8]+(C[9,5]*12+C[9,7]*24+C[9,8]*24+C[9,9]*36)/379
440 C[6,8]=C[6,8]+(C[9,10]*48+C[1,4]*G[13]*1.2+(C[9,6]+C[9,4])*12)/379
442 C[6,8]=C[6,8]-12/44/100*(F[7]*C[6,9]-Y[3]*C[1,3])
450 WRITE (15,30)"ORGANIC CARBON",C[6,7],C[6,8],"#/MIN",C[6,8]/C[6,7]
460 WRITE (15,40)C[1,3]*(P[5]-Y[3]*12/44)/100,"S"
470 WRITE (15,40)C[7,1]*P[8]/100,"O"
480 WRITE (15,40)C[6,8]-(C[1,3]*(P[5]-Y[3]*12/44)+C[7,1]*P[8])/100,"G"
```

DIRECT HEATED MODE MATERIAL BALANCE PART 2 (CONTD)

TABLE 7-3

```
490 C[3,3]=C[6,9]*P[3]/100
500 C[3,4]=(C[7,1]*P[9]+C[1,3]*P[6])/100
510 C[3,4]=C[3,4]+C[7,2]*2/18
520 C[3,4]=C[3,4]+(C[9,1]*2+C[9,5]*4+C[9,7]*4+C[9,8]*6+C[9,9]*8)/379
530 C[3,4]=C[3,4]+C[9,10]*10/379+C[1,4]/379*G[13]*0.24+C[3,8]/379*2
540 C[3,4]=C[3,4]+C[1,4]*G[14]/379*3/100
550 WRITE (15,30)"TOT. HYDROGEN",C[3,3],C[3,4],"#/MIN",C[3,4]/C[3,3]
560 WRITE (15,40)C[1,3]*P[6]/100,"S"
570 WRITE (15,40)C[7,1]*P[9]/100,"O"
580 WRITE (15,40)C[3,4]-C[1,3]*P[6]/100-C[7,1]*P[9]/100,"G+H2O"
590 C[3,5]=C[6,9]*P[4]/100
600 C[3,6]=(C[7,1]*P[10]+C[1,3]*P[7]+G[14]*C[1,4]*14/379)/100
610 WRITE (15,30)"ORG. NITROGEN"C[3,5],C[3,6],"#/MIN",C[3,6]/C[3,5]
620 C[2,3]=C[1,1]+(A[1]+A[2]+A[3])/379*29+C[3,7]-C[6,9]*F[5]/100
630 C[2,4]=C[1,4]*C[1,2]*29/379+C[7,1]
640 C[2,4]=C[2,4]+C[7,2]+C[1,3]
650 WRITE (15,30)"O'ALL WEIGHT ",C[2,3],C[2,4],"#/MIN",C[2,4]/C[2,3]
660 PRINT
670 FORMAT F8.3,X,"#/MIN C",F8.3,X,"#/MIN H",F8.3,X,"C/H COMB RATIO"
680 WRITE (15,670)C[2,6],C[2,7],C[2,6]/C[2,7]
685 C[6,5]=100*(141.5/(131.5+Y[8])*8.33*Y[6]/60)/(F[4]/100*C[6,9])
690 WRITE (15,30)Y[6]/(C[1,1]*60/2000*F[3])*100,"VOL%FA",C[6,5];"WT.%FA"
700 PRINT
705 LINK 5
710 END
```

TABLE 7-4

CALCULATED DATA ARRAY FOR DIRECT MODE MATERIAL AND HEAT BALANCES
C[10,10]

1 = Mat.Bal. Part 1

2 = Mat.Bal. Part 2

3 = Heat Bal.

	1	2	3	4	5	6	7	8	9	10
1	Dry Shale #/min. (1-120)	S.G.Wet Gas (2-70)	Ret.Shale #/min (1-130)	Dry Gas + H_2O SCFM (2-100)	N_2-SCFM IN (1-150)	N_2-SCFM OUT (1-195)	Ash In. #/min. (2-140)	Ash Out #/min (2-150)	H_2O In, #/min. (2-230)	H_2O Out, #/min. (2-240)
2	O_2-SCFM in Air (1-250)	O_2-SCFM to burn C (1-350)	Wt. In. #/min (2-620)	Wt. Out #/min (2-630)		C burned #/min (2-210)	H burned #/min (2-220)	Kerogen in,#/min (2-300)	Kerogen out #/min (2-310)	O_2-SCFM to burn H (1-370) (2-80)
3			Hydrogen in,#/min (2-490)	Hydrogen Out,#/min (2-500)	Org N in,#/min (2-590)	Org N out/#/min (2-600)	H_2O In shale #/min (1-160)	H_2O In Gas,SCFM (1-164)	Fr. H_2O Vapor In Prod Gas (1-180)	
4	H_2-SCF/T Net After F.A. H_2 (1-360)		CO_2-SCF/T Net.Comb. After F.A + Min CO_2 (3-50)	Btu/Tn $C \longrightarrow CO_2$ (3-70)	CO-SCF/T Net Comb After FA CO (3-80)	Btu/Ton $2C + O_2 \rightarrow 2CO$ (3-90)	H_2-SCF/T Comb. By O_2 (3-110)	BTU/Ton $2H_2 + O_2 \rightarrow 2H_2O$ (3-120)	C/H Comb. Ratio (3-140)	
5	Shale in Btu/T (S1) (3-154)	Air in. Btu/T (S2) (3-157)	Gas In. Btu/T (S3) (3-330)	Cooling H_2O,Btu/T (w) (3-158)	Off Gas BTU/T (S5) (3-291)	Ret.Shale Btu/T (S6) (3-400)	Oil Mist Out,Btu/T (S7) (3-430)	Latent Ht H_2O Btu/T (S8) (3-460)	Carb.Dec Btu/T (S9) (3-490)	Liq.H_2O As Gas Btu/T (S0) (3-520)
6	ΣHeat In Btu/T (I) (3-570)	ΣHeat Out Btu/T (O) (3-590)	Differn. Btu/T (U) (3-600)				Org C In #/Min (2-410)	Org C Out #/Min (2-420)		
7	Oil,#/Min (1-200)	Liquid #/Min (1-140)		Carb. Decomp. % (3-910)						
8	Dry Gas FR. H_2 (1-90→110)	FR N_2	FR O_2	FR CO	FR CH_4	FR CO_2	FR C_2H_4	FR C_2H_6	FR C_3	FR C_4
9	H_2-SCFM (1-220→240)	N_2 SCFM	O_2 SCFM	CO SCMF	CH_4 SCFM	CO_2 SCFM	C_2H_4 SCFM	C_2H_6 SCFM	C_3 SCFM	C_4 SCFM
10	Factor wet% Gas to Dry FR (1-80)	ΣG(1to10) +G(13) Ex.H_2O (1-40→70)	Prod. Gas SCFM (1-190)	O_2-SCFM to Burn C to CO_2 (1-320)		Fischer Assay H_2- SCFM (1-270)	F.A. CO SCFM (1-280)	F.A. CH_4 SCFM (1-290)	F.A. CO_2 SCFM (1-300)	F.A.C_2H_4 + C_2H_6 (1-310)

TABLE 7-5

DIRECT HEATED MODE MATERIAL BALANCES - PRELIMINARY CALCULATIONS

BASIS: DRY SHALE INPUT

C [1,3] = (Ret Shale TPH) * 2000/60 => [DRY RET SHALE #/MIN] <① - 130>

C [1,1] = (Raw Shale TPH) * 2000/60 => [DRY RAW SHALE #/MIN] <① - 120>

C [6,9] = $\dfrac{\text{C 1, 1} * 100}{[100 - \text{wt\% lab moist.}]}$ = [LAB MOIST. SHALE #/MIN] <① - 145>

FISCHER ASSAY ADJUSTMENT FIGURE TO CALCULATE
ASSUMED VALUES FOR THE PRODUCTION OF
H_2, CO, CH_4, & CO_2 BASED ON THE RAW SHALE F.A.GPT

$$K = \frac{C\ [6,9] * (\text{raw shale Fischer Assay GPT})}{2000 * 29.3}$$ <① - 260>

29.3 is the Raw Shale FA GPT from which the production figures are based

For H_2 C [10,6] = 123 * K => [SCFM H_2 from F.A] <① - 270>

For CO C [10,7] = 26 * K => [SCFM CO from F.A] <① - 280>

For CH_4 C [10,8] = 107 * K => [SCFM CH_4 from F.A] <① - 290>

For CO_2 C [10, 9] = 137 * K => [SCFM CO_2 from F.A] <① - 300>

MAT BAL PART 1 = ①
MAT BAL PART 2 = ②
HEAT BAL = ③

KEY: EACH OF THE ABOVE EXPRESSIONS IS REFERENCED TO ITS POSITION IN THE PROGRAM EXECUTION BY PROGRAM # & LINE #

<① - 100 means the expression may be found in line 100 of mat bal part 1

TABLE 7-5 (Contd)

CALCULATION OF O_2 (SCFM) TO BURN C TO CO & CO_2

1. O_2 SCFM TO BURN C TO CO_2

$$C[10,4] = (\text{SCFM } CO_2 \text{ IN PROD. GAS}) - \left[\frac{(C[6,9] * (\text{Raw Shale wt\% min } CO_2) - C[1,3] * (\text{Ret. Shale wt\% min } CO_2) * 379}{44 * 100}\right] - C[10,9]$$

<① 330>

2. O_2 SCFM TO BURN C TO CO

$$C[2,5] = (\text{SCFM CO IN PROD GAS}) - \frac{C[10,7]}{2} < ① - 340 >$$

3. O_2 SCFM TO FORM H_2O (BY DIFFERENCE ASSUMING A 100% OXYGEN BALANCE)

$$C[2,10] = \left[(\text{SCFM } O_2 \text{ INPUT IN AIR}) - C[10,4] - C[2,5] - (\text{SCFM } O_2 \text{ IN PROD GAS})\right] < ① - 370$$

RESULTS:

a. $C[2,2] = C[10,4] + C[2,5] = \text{SCFM } O_2 \text{ TO BURN C TO CO \& } CO_2] < ① - 350$

b. $\frac{C[10,4]}{379} * 12 + \left(\frac{C[2,2] - C[10,4]}{379}\right) * 24 = \text{CARBON BURNED (\#/MIN)} < ② - 210$
$C[2,6]$

c. $\frac{C[2,10] * 4}{379} = \text{HYDROGEN BURNED (\#/MIN)} < ② - 220 >$
$C\ 2,7$

d. $C/H \text{ COMB RATIO} = C[2,6]/C[2,7] < ② - 680 >$

TABLE 7-6

DIRECT HEATED MODE MATERIAL BALANCE PART 2

BALANCES

A. ATMOSPHERIC NITROGEN BALANCE

N_2 IN (SCFM) =C [1,5] = 0.79 * [TOP + MID + BTM AIR (SCFM)] <1 - 150>

N_2 OUT (SCFM) = C [1,6] = (PROD. GAS SCFM) * $\frac{\text{(VOL\% } N_2 \text{ IN PROD GAS)}}{100}$ <1 - 195>

B. ASH BALANCE

ASH IN(#/MIN) = C [1,7] = $\left[\frac{\text{DRY RAW SHALES, \#/MIN) 100}}{\text{(100 - wt\% LAB MOISTURE)}}\right]$ * $\frac{\text{(Raw Shale wt\% Ash)}}{100}$ <2 - 140>

ASH OUT (#/MIN) = C [1,8] = $\frac{\text{[RET SHALE, \#/MIN] * (Ret Shale wt\% Ash)}}{100}$ <2 - 150>

C. OXYGEN BALANCE

O_2 IN (SCFM) = C [2,1] = 0.21 * [TOP + MID + BTM AIR (SCFM)] <1 - 250>

O_2 OUT(SCFM) = C [6,6] = (SCFM O_2 TO BURN C TO CO & CO_2) + (SCFM TO BURN H TO H_2O) <2 - 170>

C [2,2] (under SCFM O_2 TO BURN C TO CO & CO_2); C [2,10] (under SCFM TO BURN H TO H_2O)

D. WATER BALANCE

H_2O IN (#/MIN) = C [1,9] = $\left[\frac{\text{(DRY RAW SHALE, \#/MIN) 100}}{\text{(100 - wt\% LAB MOISTURE)}}\right]$ * $\frac{\text{(Fischer Assay Wt\% } H_2O)}{100}$ +

$\frac{\text{(DRY RAW SHALE, \#/MIN) * (TYLAB MOISTURE, WT\%)}}{\text{(100 - TYLAB MOISTURE, WT\%)}}$ + $\frac{\text{(SCFM } O_2 \text{ TO BURN H TO } H_2O) * 36}{379}$ <2 - 230>

H_2O OUT (#/MIN) = C [1,10] = (H_2O COLLECTED, #/MIN) + $\frac{\text{(PROD. GAS SCFM) * (VOL\% } H_2O) 18}{\text{100 * (379 SCF/\# MOLE)}}$ <2 - 240>

NOTE 1: THE RETORTED SHALE IS ASSUMED TO BE DRY

NOTE 2: TYLAB MOIST. IS ON THE UNCRUSHED RAW SHALE. LAB MOIST. IS ON THE CRUSHED LAB SAMPLE.

NOTE 3: THE "H_2O IN" CALCULATION ASSUMES FISHCER ASSAY H_2O AND LAB MOISTURE TO BE INDEPENDENT. TO BE ABSOLUTELY ACCURATE, THE LAB MOISTURE SHOULD BE SUBTRACTED FROM THE FISCHER ASSAY H_2O IN THE ABOVE CALCULATION BECAUSE THE F.A. H_2O INCLUDES LAB MOISTURE.

TABLE 7-6 (Contd)

E. KEROGEN BALANCE

KEROGEN IN(#/MIN) = C[2,8] = C[6,9] * $\frac{\text{[100-(Raw shale wt\% ash)-(Raw shale wt\% min } CO_2\text{)-(Raw shale Fischer Assay wt\% } H_2O\text{]}}{100}$

<② - 300>

KEROGEN OUT (#/MIN) = C[2,9] = $\frac{1}{379} * \sum_i$ [SCFM Comp i IN PROD GAS (DRY BASIS)] * (M.W. of Comp i)

where i is all gas components except N_2, O_2, CO, CO_2, H_2O, and oil

+ (RETORTED SHALE, #/MIN) * $\frac{\text{[100 - (RET SHALE WT\% ASH) - (RET SHALE WT\% MIN } CO_2\text{)]}}{100}$ + (PROD OIL, #/MIN)

+ (HYDROGEN BURNED TO H_2O #/MIN) + $\frac{\text{[PROD GAS, SCFM (WET)] * (VOL\% OIL) * (144 \#/\# mole)}}{\left(379 \ \frac{\text{SCF}}{\text{\# mole}}\right)}$

+ (CARBON BURNED TO CO & CO_2, #/MIN) − [C[6,9] * (Raw shale wt% min CO_2) − (ret shale, #/min) * (ret shale wt% min CO_2)]

* $\frac{12}{44 * 100}$ 2 - 310 - 332

F. ORGANIC CARBON BALANCE

ORGANIC C IN (#/MIN) = C[6, 7] = C [6,9] * $\left[\frac{\text{(Raw Shale wt\%C) - (Raw Shale wt\% min } CO_2\text{) * } \frac{12}{44}}{100}\right]$ <② - 410>

ORGANIC C OUT (#/MIN) = C[6,8] = (Ret Shale #/MIN) * $\frac{\text{[(Ret Shale wt\%C)-(Ret shale wt\% min } CO_2\text{)*}\frac{12}{44}\text{+(Prod oil \#/min)*(oil wt\% C)]}}{100}$

+ $\frac{\frac{12\#C}{\#\ \text{Mole}}}{379\ \frac{\text{SCF}}{\#\ \text{mole}}}$ * $\sum_i$ (SCFM Comp i IN PROD GAS (DRY BASIS) * (NO. OF CARBON ATOMS IN COMP i)

Where i includes CH_4, C_2H_4, C_2H_6, C-3's, C-4's

+ $\frac{\text{[PROD GAS, SCFM (WET)] * (VOL\% OIL) * 1.2}}{379}$ + (CARBON BURNED TO CO & CO_2, #/MIN)

− C[6,9] * [(Raw shale wt% min CO_2) − (Ret shale, #/min) * (Ret Shale wt% min CO_2)] * $\frac{12}{44 * 100}$ <② - 420→442>

NOTE: C [6,9] = $\frac{\text{(dry raw shale, \#/min) * 100}}{\text{(100 - Raw shale wt\% Lab Moisture)}}$ = LAB MOIST. SHALE, #/MIN

TABLE 7-6 (Contd)

G. <u>TOTAL HYDROGEN BALANCE</u>

HYDROGEN IN (#/MIN) = C [3,3] = $\dfrac{C[6,9] * \text{(RAW SHALE WT\% H)}}{100}$ < ② - 490 >

HYDROGEN OUT (#/MIN) = C [3,4] = $\left[\dfrac{\text{(PROD OIL, \#/MIN)} * \text{(OIL WT\% H)} + \text{(RET SHALE \#/MIN)} * \text{(RET SHALE WT\% H)}}{100}\right]$

$+ \text{(}H_2O\text{ COLLECTED, \#/MIN)} * \dfrac{2}{18} + \dfrac{1 \ \dfrac{\#\ H}{\#\ \text{mole}}}{\dfrac{379\ \text{SCF}}{\#\text{mole}}} * \sum_i \text{(SCFM Comp i IN PROD GAS (DRY BASIS))} * \text{(no. of H Atoms in Comp i)}$

where i includes H_2, CH_4, C_2H_4, C_2H_6, C-3's & C-4's

$+ \dfrac{\text{[PROD GAS, SCFM (WET)]}}{379} * \text{(VOL\% OIL)} * 0.24 + \text{(}H_2O\text{ IN PROD GAS, SCFM)} * \dfrac{2}{379}$ < ② - 500 → 540 >

H. <u>ORGANIC NITROGEN BALANCE</u>

ORGANIC NITROGEN IN (#/MIN) = C [3,5] = $\dfrac{C[6,9] * \text{(Raw Shale wt\% N)}}{100}$ < ② - 590 >

ORGANIC NITROGEN OUT (#/MIN) = C [3,6] = $\left[\dfrac{\text{(PROD OIL,\#/MIN)} * \text{(OIL WT\% N)} + \text{(RET SHALE, \#/MIN)} * \text{(RET SHALE WT\% N}}{100}\right]$ < ② - 600 >

I. <u>OVERALL WEIGHT BALANCE</u>

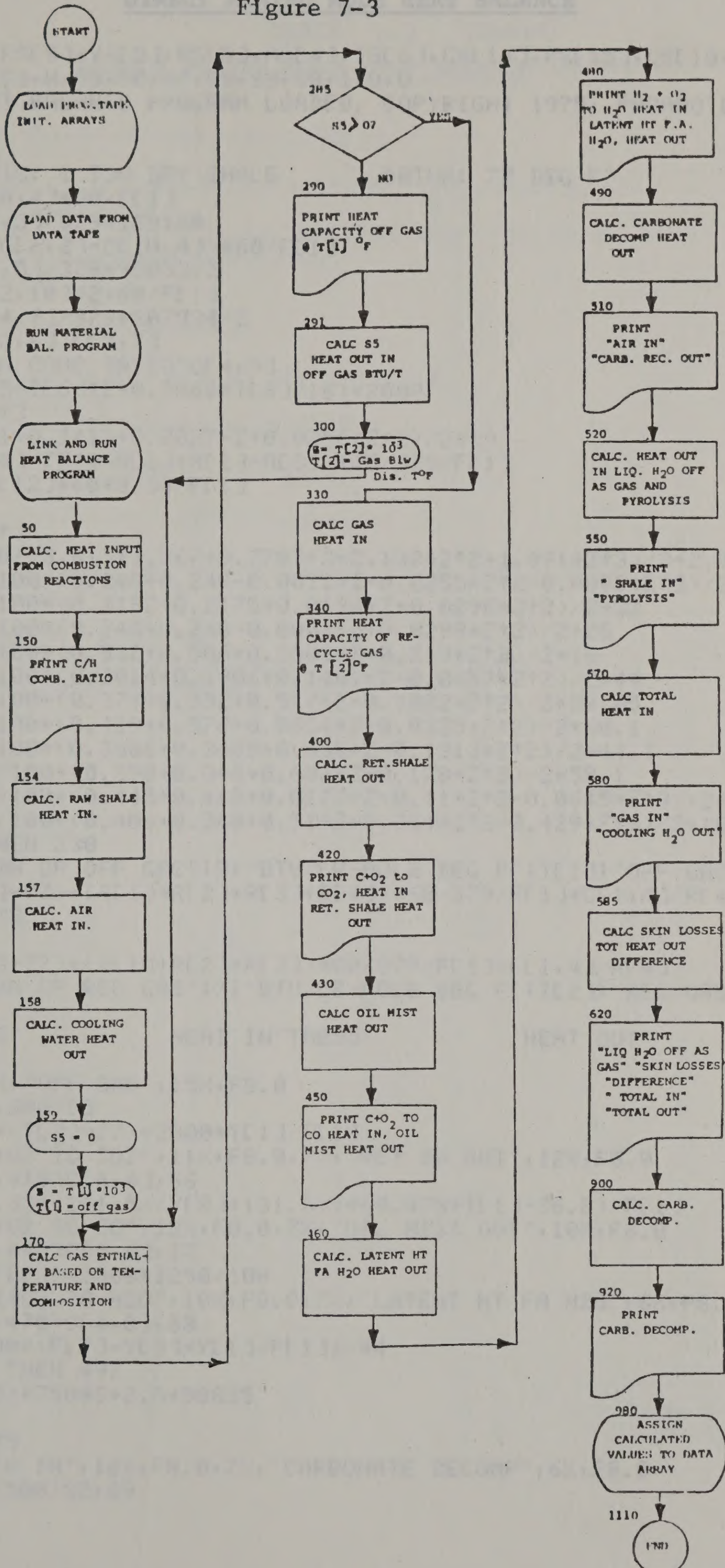
TOTAL WEIGHT IN (#/MIN) = C [2,3] = (DRY RAW SHALE,#/MIN) + (TOT AIR INPUT,#/MIN) + (H_2O IN RAW SHALE, #/MIN)

$- \left[\dfrac{\text{(DRY SHALE,\#/MIN)} * 100}{\text{(100-wt\% lab moisture)}}\right] * \dfrac{\text{(Raw shale Fischer Assay wt\% }H_2O\text{)}}{100}$ < ② - 620 >

TOTAL WEIGHT OUT (#/MIN) = C [2,4] = $\dfrac{\text{[PROD GAS, SCFM(WET)]} * \text{(SPECIFIC GRAVITY(WET GAS)} * (29 \dfrac{\#}{\#\ \text{mole}})}{379\ \dfrac{\text{SCF}}{\#\ \text{mole}}}$

+ (PROD OIL, #/MIN) + (H_2O COLLECTED, #/MIN) + (RET SHALE,#/MIN) < ② - 630,640 >

DIRECT HEATED MODE-HEAT BALANCE PROGRAM
FLOW CHART
Figure 7-3



Paraho

TABLE 7-7
DIRECT HEATED MODE HEAT BALANCE

```
10 COM HS[6],FS[9],YS[8],RS[5],AS[4],TS[6],GS[14],PS[15],CS[10,10]
11 DIM S1,S2,S3,W,S5,S6,S7,S8,S9,S0,I,O,U
20 PRINT "HEAT BALANCE PROGRAM LOADED. COPYRIGHT 1975, PARAHO DEV. CORP.
22 PRINT
23 FIXED 3
25 PRINT "BASIS: 1 TON DRY SHALE        DATUM: 77 DEG F"
50 C[4,3]=C[10,4]*60/F[1]
70 C[4,4]=C[4,3]/379*169180
80 C[4,5]=2*(C[2,2]-C[10,4])*60/F[1]
90 C[4,6]=C[4,5]/379*95033/2
110 C[4,7]=C[2,10]*2*60/F[1]
120 C[4,8]=C[4,7]/379*207934/2
140 C[4,9]=C[2,6]/C[2,7]
150 PRINT "C/H COMB RATIO"C[4,9]
154 S1=(4/10↑5*T[6]↑2+0.2068*T[6]-16)*2000
155 Z=T[4]/10↑3
156 X1=(0.2421+0.2413+0.0027*Z+0.0256*Z↑2)/2*29
157 S2=X1*(T[4]-77)*(A[1]+A[2]+A[3])*60/379/F[1]
158 W=P[11]*P[12]*60*8.33/F[1]
159 S5=0
160 Z=T[1]/10↑3
170 X=G[1]/100*(3.415+3.367+0.7783*Z-2.138*Z↑2+1.991*Z↑3)/2*2.016
180 X=X+G[2]/100*(0.248+0.248-0.0021*Z+0.0255*Z↑2-0.0008*Z↑3)/2*28
190 X=X+G[3]/100*(0.2192+0.2175+0.0194*Z+0.0296*Z↑2)/2*32
200 X=X+G[4]/100*(0.248+0.248-0.0001*Z+0.0299*Z↑2)/2*28
210 X=X+G[5]/100*(0.532+0.506+0.3303*Z+0.213*Z↑2)/2*16
220 X=X+G[6]/100*(0.2014+0.1906+0.1461*Z-0.0657*Z↑2)/2*44
230 X=X+G[7]/100*(0.371+0.332+0.517*Z-0.1022*Z↑2)/2*28.05
240 X=X+G[8]/100*(0.419+0.376+0.5634*Z-0.0225*Z↑2)/2*30.1
250 X=X+G[9]/100*(0.3986+0.3489+0.656*Z-0.1313*Z↑2)/2*44.1
260 X=X+G[10]/100*(0.398+0.346+0.682*Z-0.178*Z↑2)/2*58.1
270 X=X+G[12]/100*(0.445+0.443+0.0177*Z+0.11*Z↑2-0.0645*Z↑3)/2*18
280 X=X+G[13]/100*(0.408+0.368+0.51*Z+0.264*Z↑2-0.429*Z↑3)/2*100
285 IF S5>0 THEN 330
290 PRINT "MEAN CP OFF GAS";X;"BTU/LB-MOLE DEG F";T[1];"OFF GAS TEMP"
291 S5=X*(T[1]-77)*(R[1]+R[2]+R[3]+R[4])*60/379/F[1]*C[1,4]/R[4]
300 Z=T[2]/10↑3
301 GOTO 170
330 S3=X*(T[2]-77)*(R[1]+R[2]+R[3])*60/379/F[1]*C[1,4]/R[4]
340 PRINT "MEAN CP REC GAS";X;"BTU/LB-MOLE DEG F";T[2];"REC GAS TEMP"
350 PRINT
360 PRINT TAB5"            HEAT IN"TAB35"            HEAT OUT"
370 PRINT
380 FORMAT 37X,"OFF GAS",15X,F8.0
390 WRITE (15,380)S5
400 S6=0.2224*(T[3]-77)*2000*Y[1]/F[1]
410 FORMAT "C+O2 TO CO2",11X,F8.0,7X,"RET SH OUT",12X,F8.0
420 WRITE (15,410)C[4,4],S6
430 S7=Y[6]*8.33*(141.5/(Y[8]+131.5))*(0.478*T[1]-36.8)/F[1]
440 FORMAT "C+O2 TO CO",12X,F8.0,7X,"OIL MIST OUT",10X,F8.0
450 WRITE (15,440)C[4,6],S7
460 S8=(F[5]+F[2])*2000*1250/100
470 FORMAT "H2+O2 TO H2O",10X,F8.0,7X,"LATENT HT FA H2O",6X,F8.0
480 WRITE (15,470)C[4,8],S8
490 S9=2000/100*(F[7]-Y[3]*Y[1]/F[1])/44
491 IF S9<2.5 THEN 497
492 S9=(S9-2.5)*75095+2.5*58835
493 GOTO 500
497 S9=S9*58835
500 FORMAT "AIR IN",16X,F8.0,7X,"CARBONATE DECOMP",6X,F8.0
510 WRITE (15,500)S2,S9
```

TABLE 7-7 (Contd)

DIRECT HEATED MODE HEAT BALANCE (CONT)

```
520 S0=Y[7]*8.33*(0.417*T[1]-32.1)/F[1]
530 X2=32*2000
540 FORMAT "SHALE IN",14X,F8.0,7X,"PYROLYSIS",13X,F8.0
550 WRITE (15,540)S1,X2
560 FORMAT "GAS IN",16X,F8.0,7X,"COOLING H2O",11X,F8.0
570 I=C[4,4]+C[4,6]+C[4,8]+S1+S2+S3
580 WRITE (15,560)S3,W
585 L=10000
590 O=S5+S6+S7+S8+S9+S0+W+L+X2
600 U=I-O
610 FORMAT 37X,"LIQ H2O OFF AS GAS",4X,F8.0
620 WRITE (15,610)S0
625 FORMAT 37X,"SKIN LOSSES",11X,F8.0
626 WRITE (15,625)L
630 FORMAT 37X,"DIFFERENCE",12X,F8.0
635 WRITE (15,630)U
640 FORMAT 23X,"-------",30X,"-------"
645 WRITE (15,640)
650 FORMAT 10X,"TOTAL IN",4X,F8.0,17X,"TOTAL OUT",3X,F8.0
660 WRITE (15,650)I,O+U
895 PRINT
900 C[7,3]=2000*F[7]/100/44
910 C[7,4]=20*(F[7]-Y[3]*Y[1]/F[1])/44/C[7,3]*100
920 PRINT "CARBONATE DECOMP",C[7,4],"%"
980 C[5,1]=S1
990 C[5,2]=S2
1000 C[5,3]=S3
1010 C[5,4]=W
1020 C[5,5]=S5
1030 C[5,6]=S6
1040 C[5,7]=S7
1050 C[5,8]=S8
1060 C[5,9]=S9
1065 C[5,10]=S0
1070 C[6,1]=I
1075 C[6,2]=O
1080 C[6,3]=U
1090 PRINT
1100 PRINT
1105 STANDARD
1106 FIND 2
1110 END
```

TABLE 7-8

DIRECT HEATED MODE HEAT BALANCE

BASIS: 1 TON DRY SHALE DATUM: $77^{\circ}F$

HEAT IN

COMBUSTION REACTIONS

$C + O_2 \rightarrow CO_2$

$$\text{Btu/T} = \left[\frac{(\text{SCFM } O_2 \text{ to BURN } C \rightarrow CO_2) * (60\ \frac{\text{Min}}{\text{Hr}})}{(\text{DRY SHALE, } \frac{\text{TONS}}{\text{HR}}) * 379\ \frac{\text{SCF}}{\#\ \text{mole}}}\right] * (169180\ \frac{\text{Btu}}{\#\ \text{mole}}) \langle ③ - 70 \rangle$$

$2C + O_2 \rightarrow 2CO$

$$\text{Btu/T} = \left[\frac{2 * (\text{SCFM } O_2 \text{ TO BURN } C \rightarrow CO) * (60\ \frac{\text{Min}}{\text{Hr}})}{(\text{DRY SHALE, } \frac{\text{Tons}}{\text{Hr}}) * 379\ \frac{\text{SCF}}{\#\ \text{mole}}}\right] * (\frac{95033}{2}\ \frac{\text{Btu}}{\#\ \text{mole}}) \langle ③ - 90 \rangle$$

$2H_2 + O_2 \rightarrow 2H_2O$

$$\text{Btu/T} = \left[\frac{2 * (\text{SCFM } O_2 \text{ TO BURN } H \rightarrow H_2O * (60\ \frac{\text{Min}}{\text{Hr}})}{(\text{DRY SHALE, } \frac{\text{TONS}}{\text{Hr}})\ (379\ \frac{\text{SCF}}{\#\ \text{mole}})}\right] * (\frac{207934}{2}\ \frac{\text{Btu}}{\#\ \text{mole}}) \langle ③ - 120 \rangle$$

$$\frac{\text{AIR IN}}{\text{Btu/T}} = \left[\frac{29}{2} * \left(0.2421 + 0.2418 + 0.0027 * \frac{T[4]}{10^3} + 0.0256 * \left[\frac{T[4]}{10^3}\right]^2\right) \frac{\text{Btu}}{\text{Mol}^{\circ}F}\right] * \frac{(T[4] - 77) * (\text{SCFM AIR INPUT}) * 60\ \frac{\text{Min}}{\text{Hr}}}{379\ \frac{\text{SCF}}{\#\ \text{mole}} * (\text{DRY SHALE, } \frac{\text{TONS}}{\text{HR}})} \langle ③ - 157 \rangle$$

$T[4]$ = Air Blower Discharge T $^{\circ}F$

$$\frac{\text{SHALE IN}}{\text{Btu/T}} = \left[4 * 10^{-5} * T[6]^2 + 0.2068 * T[6] - 16\ \frac{\text{Btu}}{\#}\right] * (2000\ \#/\text{Ton}) \langle ③ - 154 \rangle$$

$T[6]$ = shale in $T^{\circ}F$

$$\frac{\text{GAS IN}}{\text{Btu/T}} = \left[\sum (\text{vol\% OF GAS COMP } i) * \left[\begin{array}{l}\text{ENTHALPY OF COMP } i \text{ AT} \\ \text{GAS BLOWER DISCHG TEMP } {}^{\circ}F\end{array}\right] * (\text{M.W. OF COMP } i)\right] \frac{\text{Btu}}{\#\ \text{mole}\ {}^{\circ}F}$$

$$* \frac{(T[2] - 77)^{\circ}F * (\text{TOT GAS SCFM}) * 60\ \frac{\text{Min}}{\text{Hr}}}{(379\ \frac{\text{SCF}}{\#\ \text{mole}}) * (\text{DRY SHALE, } \frac{\text{tons}}{\text{Hr}})} \langle ③ - 330 \rangle$$

$T[2]$ = Gas blower discharge T $^{\circ}F$

TABLE 7-8 (Contd)

HEAT OUT

$$\text{RET SHALE OUT (Btu/T)} = \frac{\left(0.2224 \frac{\text{Btu}}{\#\ ^{\circ}\text{F}}\right) * (T\ [3] - 77)^{\circ}\text{F} * \left(\frac{2000\ \#}{\text{Ton}}\right) * (\text{RET SHALE TPH})}{(\text{DRY RAW SHALE, TPH})} < ③ - 400 >$$

T [3] = Retorted shale T°F

$$\text{OIL MIST OUT (Btu/T)} = \frac{(\text{PRODUCT OIL, GPH}) * \left(\text{OIL DENSITY}, \frac{\#}{\text{Gal}}\right) * \left[\left(0.478 \frac{\text{Btu}}{\#\ ^{\circ}\text{F}}\right) * [1]\ ^{\circ}\text{F} - 36.8 \frac{\text{Btu}}{\#}\right]}{(\text{DRY RAW SHALE, TPH})} < ③ - 430 >$$

T [1] = OFF GAS T °F

$$\text{LATENT HEAT FISCHER ASSAY } H_2O \text{ (Btu/T)} = \frac{\left[(\text{Raw shale wt\%})_{\text{F.A. } H_2O} + (\text{Raw Shale wt\%})_{\text{LAB MOISTURE}}\right] * \left(\frac{2000\ \#}{\text{Ton}}\right) * 1250 \frac{\text{Btu}}{\#}}{100} < ③ - 460 >$$

CARBONATE DECOMPOSITION

$$= \frac{\left(\frac{2000\ \#}{\text{ton}}\right)}{100 \quad \left(\frac{44\ \#}{\#\ \text{mole}}\right)} * \left[(\text{Raw shale min. } CO_2\text{, wt\%}) - \frac{(\text{Ret shale min } CO_2\text{,wt\%}) * (\text{Ret shale, TPH})}{(\text{Dry Raw Shale, TPH})}\right] < ③ - 490 \longrightarrow 497 >$$

If the carbonate decomposition, measured as # mole CO_2/ton, is less than or equal to 2.5, multiply amount liberated by 58,835 Btu/# mole as the heat of decomposition of $MgCO_3$. It is assumed that all carbonate decomposition in excess of 2.5 # mole/ton production of CO_2 is liberated from the decomposition of $CaCO_3$, whose heat of decomposition is 75,096 Btu/# mole.

PYROLYSIS (Btu/T) = (32 Btu/#) * (2000 #/Ton) - 530

$$\text{COOLING } H_2O \text{ (Btu/T)} - \frac{(\text{Cooling Water, T }^{\circ}\text{F}) * (\text{Cooling Water, GPM}) * \left(60 \frac{\text{Min}}{\text{Hr}}\right) * \left(8.33 \frac{\#}{\text{Gal}}\right) * \left(1 \frac{\text{Btu}}{\#\ ^{\circ}\text{F}}\right)}{(\text{Dry Raw Shale, Tph})} < ③ - 158 >$$

$$\text{LIQ } H_2O \text{ OFF AS GAS (Btu/T)} = \frac{(H_2O \text{ Collected GPH}) * \left(8.33 \frac{\#}{\text{Gal}}\right) * \left[0.417 \frac{\text{Btu}}{\#\ ^{\circ}\text{F}} * T[1]\ ^{\circ}\text{F} - 32.1 \frac{\text{Btu}}{\#}\right]}{(\text{Dry Raw Shale, TPH})} < ③ - 520 >$$

SKIN LOSSES (Btu/T) = 10,000 Btu/Ton < ③ - 585 >

TABLE 7-8 (Contd)

$$\frac{\text{DIFFERENCE}}{\text{Btu/Ton}} = \sum \text{HEAT INPUTS} - \sum \text{HEAT OUTPUTS}$$ < 3 - 600 >

$$\frac{\text{TOTAL HEAT IN}}{\text{Btu/Ton}} = \text{COMBUSTION REACTIONS + AIR IN + SHALE IN + GAS IN.}$$ < 3 - 570 >

$$\frac{\text{TOTAL HEAT OUT}}{\text{Btu/Ton}} = \text{RET. SHALE OUT + OIL MIST OUT + LATENT HT FA } H_2O \text{ + CARBONATE DECOMPOSITION + PYROLYSIS + COOLING WATER + LIQUID WATER OFF AS GAS + SKIN LOSSES}$$ < 3 - 590 >

YIELD CALCULATIONS

$$\frac{\text{OIL COLLECTED}}{\text{VOL\% FISCHER ASSAY}} = \frac{(\text{PROD OIL GPH}) * 100}{\left(\text{DRY RAW SHALE, } \frac{\#}{\text{min}}\right) * \left(\frac{60 \text{ Min}}{\text{Hr}}\right)\left(\frac{\text{Ton}}{2000\ \#}\right) * \left(\text{RAW SHALE F.A., } \frac{\text{GAL}}{\text{TON}}\right)}$$ < 1 - 685 >

$$\frac{\text{OIL COLLECTED}}{\text{WT\% FISCHER ASSAY}} = \frac{(\text{PROD OIL, GPH}) * \left(\text{OIL DENSITY } \frac{\#}{\text{GAL}}\right) * 100}{\left(\frac{\text{Raw Shale F.A. Oil, Wt\%}}{100}\right) * \left(\text{Lab Moist Shale } \frac{\#}{\text{Min}}\right)}$$ < 1 - 690 >

NOTE: The vol% F.A. calculation is based on dry shale, the wt% F.A. calculation is based on lab moist shale which includes the wt% lab moisture.

$$\frac{\text{CARBONATE DECOMPOSITION}}{\text{Wt\%}} = \left[\frac{(\text{Raw shale min } CO_2\text{, Wt\%}) - \dfrac{(\text{Ret shale min } CO_2\text{, wt\%}) * (\text{Ret shale, TPH})}{(\text{Raw shale, TPH})}}{(\text{Raw shale min } CO_2\text{, wt\%})}\right] * 100$$ < 3 - 900,910 >

TABLE 7-9

```
H(6)
UNIT 2    RUN 20    TEST 1.15916    MMDDYY 0    HRS 303    0
F(9)
DRY SH,TPH 11.17    MOIST.% 0.96    FA,GPT 27.2    FA OIL,WT% 10.39
FA H2O 1.66    FA G+L 2.29    MIN CO2 17.71    ASH 66.93    LAB MOIST 0.71
Y(8)
RET.SH,TPH 9.15166    FA GPT 0.28    MIN CO2 15.86    ASH 82.28
H2O IN OIL,WT% 4.8  DRY OIL,GPH 290.69  H2O LIQ,GPH 12.95    API 21.4
R(5)
BTM GAS,SCFM 2255    MID 245  TOP 254  PROD 1340      H2O PPH 0
A(4)
BTM AIR,SCFM 0    MID 158  TOP 709    1.016
T(6)
OFF GAS,F 145  GAS BL DIS 241  RET SH 384  AIR BL DIS 184
PROD OIL 139  SHALE IN 36
G(14),ALL MOL%
H2 2.07    N2 54.20    O2 0.01    CO 2.08    CH4 1.82    CO2 19.99
C2H4 0.55    C2H6 0.51    C3S 0.59    C4S 0.30      0.00    H2O,G 17.55
COND.OIL 0.34      0.00
P(15)
BARO 23.94    RAW%C 17.05    H 1.84    N 0.51    RET C 6.3   H 0.17
N 0.21    OIL C 84.62    H 11.5    N 2    CWDT 18    GPM 80
MAT. BAL. PROG. LOADED. COPYRIGHT 1975,PARAHO DEV.CORP
NOW RUN70
BALANCES           IN              OUT            UNITS           FR.REC.

ATM. NITROGEN   684.93          726.29           SCFM            1.060
ASH             250.93          251.00           #/MIN           1.000
OXYGEN          182.07          181.94           SCFM            0.999
                                 81.53 TO H2O
                                100.41 TO CO&CO2
WATER             17.53          12.97           #/MIN           0.738
                   9.83 S         1.80 L
                   6.43 C        11.17 V
KEROGEN           51.37          53.82           #/MIN           1.048
                                  5.67 S
                                 37.35 O
                                 10.79 G
ORGANIC CARBON    45.32          46.44           #/MIN           1.013
                                  6.02 S
                                 31.60 O
                                  8.81 G
TOT. HYDROGEN      6.90           7.40           #/MIN           1.073
                                  0.52 S
                                  4.30 O
                                  2.59 G+H2O
ORG. NITROGEN      1.91           1.39           #/MIN           0.726
O'ALL WEIGHT     442.23         448.37           #/MIN           1.014
   3.548 #/MIN C   0.860 #/MIN H   4.123 C/H COMB RATIO
   95.68      VOL%FA    95.99           WT.%FA
HEAT BALANCE PROGRAM LOADED. COPYRIGHT 1975, PARAHO DEV. CORP.

BASIS: 1 TON DRY SHALE          DATUM: 77 DEG F
C/H COMB RATIO 4.123
MEAN CP OFF GAS 7.887   BTU/LB-MOLE DEG F 145.000    OFF GAS TEMP
MEAN CP REC GAS 7.983   BTU/LB-MOLE DEG F 241.000    REC GAS TEMP

                HEAT IN                            HEAT OUT

                                     OFF GAS                    31120
C+O2 TO CO2          212828          RET SH OUT                111879
C+O2 TO CO            15687          OIL MIST OUT                6522
H2+O2 TO H2O         240265          LATENT HT FA H2O           65500
AIR IN                 9251          CARBONATE DECOMP          126115
SHALE IN             -17007          PYROLYSIS                  64000
GAS IN                51132          COOLING H2O                64433
                                     LIQ H2O OFF AS GAS           274
                                     SKIN LOSSES                10000
                                     DIFFERENCE                 32313
                    -------                                   -------
       TOTAL IN      512156                  TOTAL OUT         512156

CARBONATE DECOMP                 26.628         %
```

7.3 INDIRECT HEATED MODE

A flow chart of the Indirect Heated Mode material balance is presented in Figure 7-4. The program listing for Part 1 is presented in Table 7-10 and for Part 2 in Table 7-11. There are no combustion calculations in this balance. In view of this, the water balance is slightly modified from the basis used for the Direct Heated Mode material balance. The material balance excludes recycle gas streams. The calculated data array is shown in Table 7-12.

The partial balances and the overall balance are discussed in Table 7-13 (5 pages).

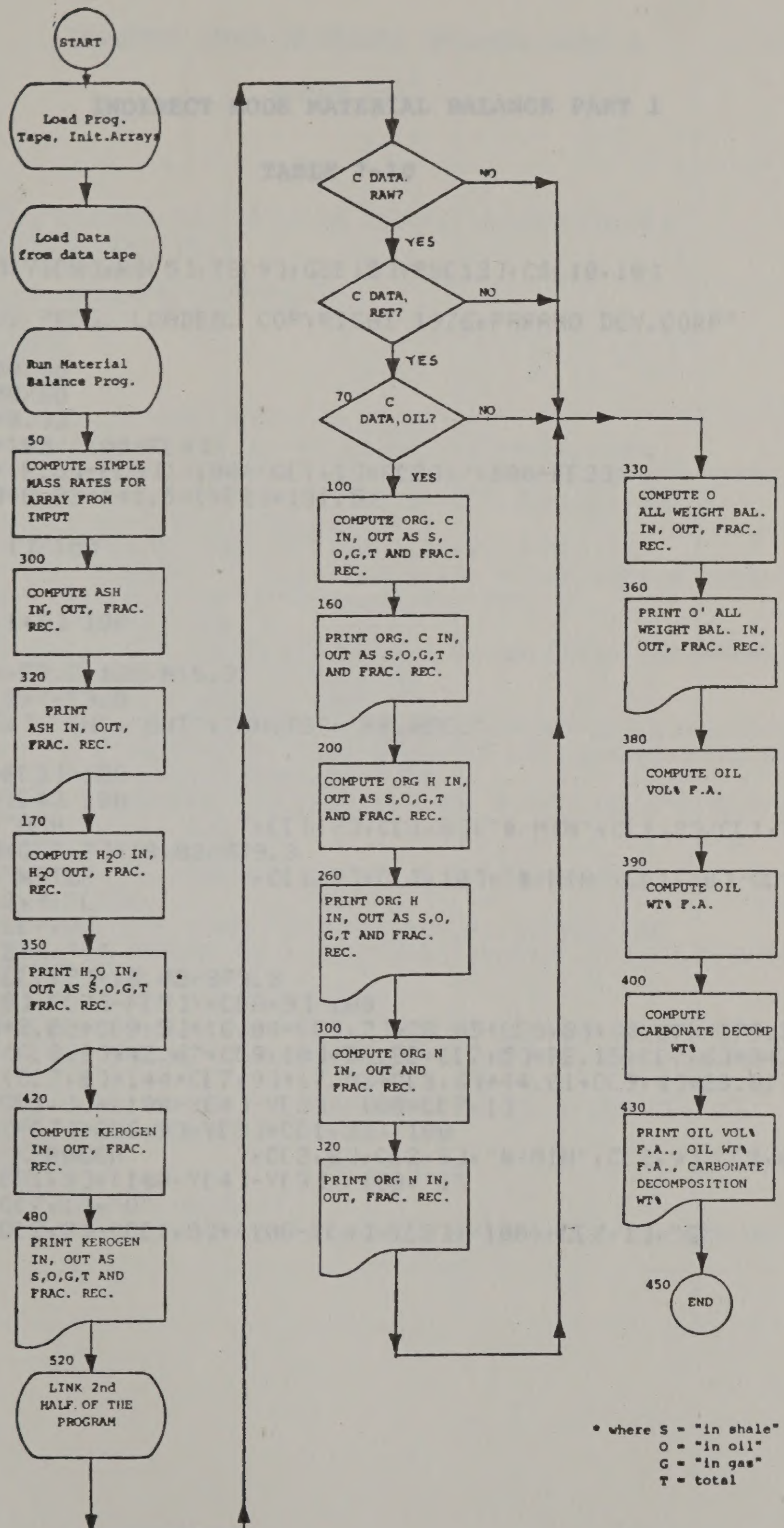
ALTERNATE MATERIAL BALANCE - C_5+ LIQ. BASIS

A slightly different Indirect Heated Mode material balance is used to calculate C5+ Liquid Basis Yield. Table 7-14 is the program listing for Part 1 and Table 7-15 lists Part 2. See Table 7-16 for the principal factors in C_5+ liquid yield calculations.

HEAT BALANCE

The flow chart of the heat balance for the Indirect Heated Mode is presented as Figure 7-6. The program listing is Table 7-17 (five pages). Some of these calculations are explained in Table 7-18 (2 pages).

INDIRECT HEATED MODE MATERIAL BALANCE
COMPUTER PROGRAM FLOW CHART Figure 7-4



INDIRECT MODE MATERIAL BALANCE PART 1

TABLE 7-10

```
10 COM HS[6],FS[9],YS[8],RS[5],TS[9],GS[15],PS[13],CS[10,10]
30 PRINT
40 PRINT "MAT. BAL. PROG. LOADED. COPYRIGHT 1976,PARAHO DEV.CORP"
50 C[1,2]=R[5]
60 C[1,1]=F[1]*2000/60
70 C[1,3]=Y[1]*2000/60
80 C[7,2]=Y[7]/60*8.33
160 C[6,9]=C[1,1]*100/(100-F[9])
170 C[1,9]=C[6,9]*(F[5]-F[9])/100+(C[1,1]*F[2])/(100-F[2])
180 C[7,1]=Y[6]/60*8.33*141.5/(Y[8]+131.5)
190 FOR I=1 TO 10
200 C[9,I]=R[4]*G[I]/100
210 NEXT I
220 FOR I=5 TO 9
230 C[7,I]=R[4]*G[I+5]/100
240 NEXT I
260 FORMAT F8.2,5X,F8.2,12X,F15.3
270 FORMAT 27X,F8.2,X,F8.0
280 PRINT "BALANCES","IN","OUT","UNITS","FR.REC."
290 PRINT
300 C[1,7]=C[6,9]*F[3]/100
310 C[1,8]=C[1,3]*Y[4]/100
320 WRITE (15,260)"ASH             ",C[1,7],C[1,8],"#/MIN",C[1,8]/C[1,7]
340 C[1,10]=C[7,2]+C[7,7]*18.02/379.3
350 WRITE (15,260)"WATER           ",C[1,9],C[1,10],"#/MIN",C[1,10]/C[1,9]
360 FORMAT 27X,F8.2,X,"L"
370 WRITE (15,360)C[7,2]
380 FORMAT 27X,F8.2,X,"V"
390 WRITE (15,380)C[7,7]*18.02/379.3
420 C[2,8]=(100-F[8]-F[7]-F[5])*C[6,9]/100
430 C[2,9]=(C[9,1]*2.02+C[9,5]*16.04+C[9,7]*28.05+C[9,8]*30.07)/379.3
440 C[2,9]=C[2,9]+(C[9,9]*42.67+C[9,10]*56.99+C[7,5]*72.15+C[7,6]*34.08)/379.3
450 C[2,9]=C[2,9]+(C[7,8]*144+C[7,9]*17.03+C[9,6]*44.01+C[9,4]*28.01)/379.3
460 C[2,9]=C[2,9]+C[1,3]*(100-Y[4]-Y[3])/100+C[7,1]
470 C[2,9]=C[2,9]-(F[7]*C[6,9]-Y[3]*C[1,3])/100
480 WRITE (15,260)"KEROGEN         ",C[2,8],C[2,9],"#/MIN",C[2,9]/C[2,8]
490 WRITE (15,270)C[1,3]*(100-Y[4]-Y[3])/100,"S"
500 WRITE (15,270)C[7,1],"O"
510 WRITE (15,270)C[2,9]-(C[1,3]*(100-Y[4]-Y[3])/100)-C[7,1],"G"
520 LINK 4
530 END
```

INDIRECT MODE MATERIAL BALANCE PART 2

TABLE 7-11

```
10 COM HS[6],FS[9],YS[8],RS[5],TS[9],GS[15],PS[13],CS[10,10]
20 FORMAT F8.2,5X,F8.2,12X,F15.3
30 FORMAT 27X,F8.2,X,F3.0
40 FORMAT F8.2,2X,F8.2,2X,F8.2,2X,F8.2
50 DISP "NOW RUN 70"
70 IF P[2]=0 THEN 330
80 IF P[5]=0 THEN 330
90 IF P[8]=0 THEN 330
100 C[6,7]=C[6,9]*(P[2]-F[7]*12.01/44.01)/100
110 C[6,8]=(C[1,3]*(P[5]-Y[3]*12.01/44.01)+C[7,1]*P[8])/100
120 C[6,8]=C[6,8]+(C[9,5]*12.01+C[9,7]*24.02+C[9,8]*24.02+C[9,9]*36.03)/379.3
130 C[6,8]=C[6,8]+(C[7,5]*60.06+C[9,10]*48.04+C[7,8]*120)/379.3
140 C[6,8]=C[6,8]+(C[9,6]+C[9,4])*12.01/379.3
150 C[6,8]=C[6,8]-12.01/44.01/100*(F[7]*C[6,9]-Y[3]*C[1,3])
160 WRITE (15,20)"ORG. CARBON    ",C[6,7],C[6,8],"#/MIN",C[6,8]/C[6,7]
170 WRITE (15,30)C[1,3]*(P[5]-Y[3]*12.01/44.01)/100,"S"
180 WRITE (15,30)C[7,1]*P[8]/100,"O"
190 WRITE (15,30)C[6,8]-(C[1,3]*(P[5]-Y[3]*12.01/44.01)+C[7,1]*P[8])/100,"G"
200 C[3,3]=C[6,9]*(P[3]-F[5]*2.02/18.02)/100
210 C[3,4]=(C[7,1]*P[9]+C[1,3]*P[6])/100
230 C[3,4]=C[3,4]+(C[9,1]*2.02+C[9,5]*4.03+C[9,7]*4.03+C[9,8]*6.05)/379.3
240 C[3,4]=C[3,4]+(C[9,9]*6.64+C[9,10]*8.95+C[7,5]*12.09+C[7,6]*2.02)/379.3
250 C[3,4]=C[3,4]+(C[7,8]*24+C[7,9]*3.02)/379.3
260 WRITE (15,20)"ORG. HYDROGEN ",C[3,3],C[3,4],"#/MIN",C[3,4]/C[3,3]
270 WRITE (15,30)C[1,3]*P[6]/100,"S"
280 WRITE (15,30)C[7,1]*P[9]/100,"O"
290 WRITE (15,30)C[3,4]-C[1,3]*P[6]/100-C[7,1]*P[9]/100,"G"
300 C[3,5]=C[6,9]*P[4]/100
310 C[3,6]=(C[7,1]*P[10]+C[1,3]*P[7]+C[7,9]*14.01/3.793)/100
320 WRITE (15,20)"ORG. NITROGEN "C[3,5],C[3,6],"#/MIN",C[3,6]/C[3,5]
330 C[2,3]=C[1,1]*(1+F[2]/(100-F[2]))
340 C[2,4]=R[4]*C[1,2]*28.97/379.3+C[7,1]
350 C[2,4]=C[2,4]+C[7,2]+C[1,3]
360 WRITE (15,20)"O'ALL WEIGHT   ",C[2,3],C[2,4],"#/MIN",C[2,4]/C[2,3]
370 PRINT
380 C[6,5]=100*(141.5/(131.5+Y[8])*8.33*Y[6]/60)/(F[4]/100*C[6,9])
390 C[6,4]=Y[6]/(C[6,9]*60/2000*F[3])*100
400 C[7,3]=C[6,9]*F[7]
410 C[7,4]=C[1,3]*Y[3]
420 C[7,10]=(C[7,3]-C[7,4])*100/C[7,3]
430 WRITE (15,40)C[6,4],"VOL%FA",C[6,5],"WT.%FA",C[7,10],"% CARB DEC"
440 PRINT
445 LINK 5
450 END
```

CALCULATED DATA ARRAY FOR INDIRECT HEATED MODE BALANCE

TABLE 7-12

C(10,10) J	1	2	3	4	5	6	7	8	9	10
1	Raw Shale Dry #/min	S.G. Wet Gas (as re-ported)	RETORTED SHALE #/min.				ASH IN #/min	ASH OUT #/min	H_2O IN #/min	H_2O OUT #/min.
2			TOTAL WT IN #/min	TOTAL WT. OUT #/min.				KEROGEN IN #/Min.	KEROGEN OUT #/Min.	
3			TOTAL H_2 IN #/min	TOTAL H_2 OUT #/Min.	ORGANIC N_2 IN #/min	ORGANIC N_2 OUT 3/min.				
4										
5	HEAT IN RAW SHALE BTU/TON	HEAT IN OIL COND. BTU/TON	HEAT IN RECL. GAS BTU/TON		HEAT OUT OFF GAS BTU/TON	HEAT OUT RET.SHALE BTU/TON	HEAT OUT OIL MIST BTU/TON	HEAT OUT H_2O VAP. BTU/TON	HEAT OUT CARB.DEC. BTU/TON	HEAT OUT H_2O VAPOR BTU/TON
6	TOTAL HEAT IN BTU/TON	TOTAL HEAT OUT BTU/Tn	HEAT DIFFER. BTU/TON	YIELD VOL% F.A.	YIELD WT% F.A.		ORGANIC C IN #/Min.	ORGANIC C OUT #/Min	MOIST RAW SHALE #/Min	REC.COND. H_2O OUT #/Min
7	PRODUCT OIL #/Min	H_2O w/oil #/min	MINERAL CO_2 IN #/Min	MINERAL CO_2 OUT #/min.	C_5 OUT IN PRODUCT GAS SCFM	H_2S OUT IN PROD. GAS SCFM	H_2O OUT IN PROD. GAS SCFM	OIL OUT IN PROD. GAS SCFM	NH_3 OUT IN PROD. GAS SCFM	CARBONATE DECOMP. %
8										
9	H_2 OUT IN PROD. GAS SCFM	N_2 OUT IN PROD. GAS SCFM	O_2 OUT IN PROD. GAS SCFM	CO OUT IN PROD. GAS SCFM	CH_4 OUT IN PROD. GAS SCFM	CO_2 OUT IN PROD. GAS SCFM	C_2H_4 OUT IN PROD. GAS SCFM	C_2H_6 OUT IN PROD. GAS. SCFM	C_3's OUT IN PROD. GAS SCFM	C_4's OUT IN PROD. GAS SCFM

TABLE 7-13

BASIS: 1 TON DRY SHALE

INDIRECT MATERIAL BALANCE

ASH BALANCE

$$\text{ASH IN \#/min.} = \left[\frac{\text{(dry raw shale in, \#/min)(100)}}{\text{(100-wt.\% lab moisture)}}\right]\left[\frac{\text{(wt.\% ash in raw shale)}}{100}\right]$$

to convert from dry to wet basis

$$\text{ASH OUT \#/min.} = \text{(retorted shale out,\#/min)}\frac{\text{(wt.\% ash in retorted shale)}}{100}$$

KEROGEN BALANCE

$$\text{KEROGEN IN \#/min} = (100 - \text{wt\% ash} - \text{wt\% mineral } CO_2 - \text{wt\% Fischer Assay } H_2O) \times \left[\frac{\text{(dry raw shale in, \#/min)(100)}}{(100 - \text{wt\% lab moisture})}\right]$$

$$\text{KEROGEN OUT \#/min} = \frac{\text{(product gas, SCFM)}}{\text{(379.3 SCF/\# mol)(100)}}\sum_i \text{(volume \% of comp. i)(M.W. of comp. i)}$$

where i is all gas componenets except N_2, O_2 and H_2O

$$+ \text{(retorted shale out,\#/min)}\frac{(100 - \text{wt\% mineral } CO_2 - \text{wt\% ash})}{100} + \text{(product oil, \#/min)}$$

$$- \frac{\left[(\text{wt\% mineral } CO_2)\dfrac{\text{(raw shale in,\#/min)(100)}}{(100 - \text{wt\% lab moisture})} - (\text{wt\% mineral } CO_2)\text{(retorted shale out, \#/min)}\right]}{100}$$

adjustment to 1st term for release of mineral CO_2

TABLE 7-13 (Contd)

WATER BALANCE

$$\text{WATER IN \#/min} = \left[\frac{(\text{dry raw shale in,\#/min})(100)}{(100 - \text{wt\% lab moisture})}\right] \frac{(\text{Fischer Assay wt\% } H_2O - \text{lab moisture wt\% net})}{100}$$

$$+ \frac{(\text{dry raw shale in,\#/min})(\text{tylab moisture,wt\%})}{(100 - \text{tylab moisture, wt\%})}$$

$$\text{WATER OUT \#/min} = (H_2O \text{ out in oil \& condensate,\#/min}) + \frac{(\text{product gas, SCFM})(\text{Volume \% } H_2O)(18.2\#/\#\text{mole})}{(100)\ (379.3\ \text{SCF/\# mol})}$$

NOTE: It is assumed that the retorted shale is totally water-free. This was confirmed by several specially handled retorted shale samples.

TABLE 7-13 (Contd)

TOTAL HYDROGEN BALANCE

$$\text{TOTAL HYDROGEN IN \#/min} = \frac{\text{(dry raw shale in,\#/min)}}{\text{(100 - wt\% lab moisture)}} \left[\frac{\text{(wt\% } H_2 \text{ in raw shale)} - \text{(wt\% lab moisture)} \, 2.02/18.02}{100} \right]$$

$$+ \left[\frac{\text{(dry raw shale in,\#/min)(wt\% tylab moisture)}}{\text{(100 - wt\% tylab moisture)}} \right] \frac{2.02}{18.02}$$

$$\text{TOTAL HYDROGEN OUT \#/min} = \frac{\text{(product oil out,\#/min)(wt\% H in oil)} + \text{(retorted shale out \#/min)(Wt\% H in retorted shale)}}{100}$$

$$+ \text{(} H_2O \text{ in product oil and condensate,\#/min)} \left(\frac{2.02}{18.02} \right)$$

$$+ \frac{\text{(1.01 \#H/\#mol)(product gas, SCFM)}}{\text{(100)(379.3 SCF/\# mol)}} \sum_{i} \text{(volume \% of H bearing Gas comp. i) (No. of H atoms in comp. i)}$$

summed over all hydrogen bearing components

TABLE 7-13 (Contd)

ORGANIC CARBON BALANCE

$$\text{ORGANIC CARBON IN \#/min} = \left[\frac{(\text{dry raw shale in, \#/min})(100)}{(100 - \text{wt\% lab moisture})}\right]\left[\frac{(\text{wt\% C in raw shale}) - (\text{wt\% mineral } CO_2)\ \frac{12.01}{44.01}}{100}\right]$$

$$\text{ORGANIC CARBON OUT \#/min} = (\text{retorted shale, \#/min})\left[(\text{wt\% C in retorted shale}) - (\text{wt\% mineral } CO_2)\ \frac{12.01}{44.01}\right]$$

$$+ (\text{product oil, \#/min})\ (\text{wt\% C in oil})$$

$$+ \frac{(12.01\ \frac{\#C}{\#mol})\ (\text{product gas, SCFM})}{(379.3\ \text{SCF/\#mol})(100)} \sum_i (\text{Volume \% of C bearing gas comp. i})\ (\text{No. of Carbons in comp. i})$$

summed over all carbon bearing gas components

$$- \frac{(12.01)}{(44.01)(100)}\left[(\text{wt\% mineral } CO_2)\frac{(\text{dry raw shale in,\#min})(100)}{(100 - \text{wt\% lab moisture})} - (\text{wt\% mineral } CO_2)(\text{retorted shale out, \#/min})\right]$$

adjustment to remove mineral CO_2 from organic carbon balance.

CARBONATE DECOMPOSITION

$$\text{CARBONATE DECOMPOSITION WT\%} = \frac{\left[\frac{(\text{dry raw shale,\#/min})(100)(\text{wt\% mineral } CO_2)}{(100 - \text{wt\% lab moisture})} - (\text{retorted shale,\#/min})(\text{wt\% mineral } CO_2)\right](100)}{\frac{(\text{dry raw shale,\#/min})(100)}{(100 - \text{wt\% lab moisture})}\ (\text{wt\% mineral } CO_2)}$$

TABLE 7-13 (Contd)

ORGANIC NITROGEN BALANCE

$$\text{ORGANIC NITROGEN IN \#/min} = \frac{\text{(dry raw shale in,\#/min)(100)}}{\text{(100 - wt\% lab moisture)}} \; \frac{\text{(wt\% N in raw shale)}}{\text{(100)}}$$

$$\text{ORGANIC NITROGEN OUT \#/min} = \frac{\left[\begin{array}{l}\text{(product oil,\#/min)(wt\% N in oil) + (retorted shale,\#/min)(wt\% N in shale)} \\ + \text{ (}NH_3\text{ in product gas, SCFM) } \left(14.01 \; \frac{\text{\# N}}{\text{\#mol}}\right) \left(\frac{3.793 \text{ HSCF}}{\text{\# mol}} \right)\end{array}\right]}{100}$$

OVERALL BALANCE

$$\text{TOTAL WEIGHT IN \#/min} = \text{(dry raw shale in,\#/min)} \left[1 + \frac{\text{(tylab moisture, wt\%)}}{\text{(100 - tylab moisture, wt\%)}} \right]$$

$$\text{TOTAL WEIGHT OUT \#/min} = \frac{\text{(product gas, SCFM)}}{\text{(379.3 SCF/\# mol)}} \text{(specific gravity of gas)(28.97) + (product oil,\#/min)}$$

$$+ \text{ (}H_2O\text{ in oil \& condensate, \#/min) + (retorted shale, \#/min)}$$

INDIRECT MODE MATERIAL BALANCE

for C5+ LIQ. BASIS PART 1

TABLE 7-14

```
10 COM HS[6],FS[9],YS[8],RS[5],TS[9],GS[15],PS[13],CS[10,10]
20 PRINT
30 Z1=0
40 PRINT "MAT. BAL. PROG. LOADED. COPYRIGHT 1976,PARAHO DEV.CORP"
50 PRINT "INPUT VOL% LT & HEAVY NAP IN GAS, & THEIR LIQ API'S"
60 INPUT G[11],G[14],A1,A2
70 PRINT G[11],G[14],A1,A2
80 M1=504.6619-12.2636*A1+0.0921*A1↑2
90 M2=504.6619-12.2636*A2+0.0921*A2↑2
100 C[7,5]=R[4]*G[11]/100
110 C[7,8]=R[4]*G[14]/100
120 C[4,1]=C[7,5]/379*M1+C[7,8]/379*M2
130 C[4,2]=8.341*(141.5/(131.5+(G[11]*A1+G[14]*A2)/(G[11]+G[14])))
140 C[4,3]=C[4,1]*60/C[4,2]
150 C[1,2]=R[5]
160 C[1,1]=F[1]*2000/60
170 C[1,3]=Y[1]*2000/60
180 C[7,2]=Y[7]/60*8.337
190 C[6,9]=C[1,1]*100/(100-F[9])
200 C[4,5]=C[7,5]/379*M1*60/(8.33*(141.5/(131.5+A1)))/(C[6,9]*60/2000)
210 C[4,6]=C[7,8]/379*M2*60/(8.33*(141.5/(131.5+A2)))/(C[6,9]*60/2000)
220 C[4,7]=(C[7,5]*M1+C[7,8]*M2)/379
230 PRINT "LT NAP=";C[4,5];"GAL/TON, HEAVY NAP=";C[4,6];"GAL/TON"
240 C[1,9]=C[6,9]*(F[5]-F[9])/100+(C[1,1]*F[2])/(100-F[2])
250 C[7,1]=Y[6]/60*8.33*141.5/(Y[8]+131.5)
260 FOR I=1 TO 10
270 C[9,I]=R[4]*G[I]/100
280 NEXT I
290 FOR I=6 TO 7
300 C[7,I]=R[4]*G[I+5]/100
310 IF Z1=1 THEN 350
320 NEXT I
330 I=9
340 Z1=1
350 FORMAT F8.2,5X,F8.2,12X,F15.3
360 FORMAT 27X,F8.2,X,F3.0
370 PRINT "BALANCES","IN","OUT","UNITS","FR.REC."
380 PRINT
390 C[1,7]=C[6,9]*F[8]/100
400 C[1,8]=C[1,3]*Y[4]/100
410 WRITE (15,350)"ASH              ",C[1,7],C[1,8],"#/MIN",C[1,8]/C[1,7]
420 C[1,10]=C[7,2]+C[7,7]*18.02/379.3
430 WRITE (15,350)"WATER            ",C[1,9],C[1,10],"#/MIN",C[1,10]/C[1,9]
440 FORMAT 27X,F8.2,X,"L"
450 WRITE (15,440)C[7,2]
460 FORMAT 27X,F8.2,X,"V"
470 WRITE (15,460)C[7,7]*18.02/379.3
480 C[2,8]=(100-F[8]-F[7]-F[5])*C[6,9]/100
490 C[2,9]=(C[9,1]*2.02+C[9,5]*16.04+C[9,7]*28.05+C[9,8]*30.07)/379.3
500 C[2,9]=C[2,9]+(C[9,9]*42.67+C[9,10]*56.99+C[7,6]*34.08)/379.3
510 C[2,9]=C[2,9]+(C[7,9]*17.03+C[9,6]*44.01+C[9,4]*28.01)/379.3
520 C[2,9]=C[2,9]+C[1,3]*(100-Y[4]-Y[3])/100+C[7,1]+C[4,1]
530 C[2,9]=C[2,9]-(F[7]*C[6,9]-Y[3]*C[1,3])/100
540 WRITE (15,350)"KEROGEN          ",C[2,8],C[2,9],"#/MIN",C[2,9]/C[2,8]
550 WRITE (15,360)C[1,3]*(100-Y[4]-Y[3])/100,"S"
560 WRITE (15,360)C[7,1]+C[4,1],"O"
570 WRITE (15,360)C[2,9]-(C[1,3]*(100-Y[4]-Y[3])/100)-C[7,1]-C[4,1],"G"
580 LINK 7
590 END
```

INDIRECT MODE MATERIAL BALANCE
FOR C5+ LIQ. BASIS PART 2

TABLE 7-15

```
10 COM H$[6],F$[9],Y$[8],R$[5],T$[9],G$[15],P$[13],C$[10,10]
20 FORMAT F8.2,5X,F8.2,12X,F15.3
30 FORMAT 27X,F8.2,X,F3.0
40 FORMAT F8.2,2X,F8.2,2X,F8.2,2X,F8.2
50 DISP "NOW RUN 70"
70 IF P[2]=0 THEN 330
80 IF P[5]=0 THEN 330
90 IF P[8]=0 THEN 330
95 Y=C[4,1]
100 C[6,7]=C[6,9]*(P[2]-F[7]*12.01/44.01)/100
110 C[6,8]=(C[1,3]*(P[5]-Y[3]*12.01/44.01)+(C[7,1]+Y)*P[8])/100
120 C[6,8]=C[6,8]+(C[9,5]*12.01+C[9,7]*24.02+C[9,8]*24.02+C[9,9]*36.03)/379.3
130 C[6,8]=C[6,8]+(C[9,10]*48.04)/379.3
140 C[6,8]=C[6,8]+(C[9,6]+C[9,4])*12.01/379.3
150 C[6,8]=C[6,8]-12.01/44.01/100*(F[7]*C[6,9]-Y[3]*C[1,3])
160 WRITE (15,20)"ORG. CARBON    ",C[6,7],C[6,8],"#/MIN",C[6,8]/C[6,7]
170 WRITE (15,30)C[1,3]*(P[5]-Y[3]*12.01/44.01)/100,"S"
180 WRITE (15,30)(C[7,1]+Y)*P[8]/100,"O"
190 WRITE (15,30)C[6,8]-(C[1,3]*(P[5]-Y[3]*12.01/44.01)+(C[7,1]+Y)*P[8])/100,"G"
200 C[3,3]=C[6,9]*(P[3]-F[5]*2.02/18.02)/100
210 C[3,4]=((C[7,1]+Y)*P[9]+C[1,3]*P[6])/100
230 C[3,4]=C[3,4]+(C[9,1]*2.02+C[9,5]*4.03+C[9,7]*4.03+C[9,8]*6.05)/379.3
240 C[3,4]=C[3,4]+(C[9,9]*6.64+C[9,10]*8.95+C[7,6]*2.02)/379.3
250 C[3,4]=C[3,4]+(C[7,9]*3.02)/379.3
260 WRITE (15,20)"ORG. HYDROGEN ",C[3,3],C[3,4],"#/MIN",C[3,4]/C[3,3]
270 WRITE (15,30)C[1,3]*P[6]/100,"S"
280 WRITE (15,30)(C[7,1]+Y)*P[9]/100,"O"
290 WRITE (15,30)C[3,4]-C[1,3]*P[6]/100-(C[7,1]+Y)*P[9]/100,"G"
300 C[3,5]=C[6,9]*P[4]/100
310 C[3,6]=((C[7,1]+Y)*P[10]+C[1,3]*P[7]+C[7,9]*14.01/3.793)/100
320 WRITE (15,20)"ORG. NITROGEN "C[3,5],C[3,6],"#/MIN",C[3,6]/C[3,5]
330 C[2,3]=C[1,1]*(1+F[2]/(100-F[2]))
340 C[2,4]=R[4]*C[1,2]*28.97/379.3+C[7,1]+Y
350 C[2,4]=C[2,4]+C[7,2]+C[1,3]
360 WRITE (15,20)"O'ALL WEIGHT  ",C[2,3],C[2,4],"#/MIN",C[2,4]/C[2,3]
370 PRINT
380 C[6,5]=100*(C[4,7]+(141.5/(131.5+Y[8])*8.33*Y[6]/60))/(F[4]/100*C[6,9])
390 C[6,4]=(Y[6]+C[4,3])/(C[6,9]*60/2000*F[3])*100
400 C[7,3]=C[6,9]*F[7]
410 C[7,4]=C[1,3]*Y[3]
420 C[7,10]=(C[7,3]-C[7,4])*100/C[7,3]
430 WRITE (15,40)C[6,4],"VOL%FAC5+LIQYIELD",C[6,5],"WT.%FA",C[7,10],"% CARB DEC"
440 PRINT
445 LINK 5
450 END
```

TABLE 7-16

C5+ LIQUID YIELD CALCULATIONS

$$\text{M.W. of LIGHT NAPHTHA} = 504.66 - 12.66(\text{light naphtha }^{\circ}\text{API}) + 0.0921\ (\text{light naphtha }^{\circ}\text{API})^2$$

$$\text{M.W. of HEAVY NAPHTHA} = 504.66 - 12.66\ (\text{heavy naphtha }^{\circ}\text{API}) + 0.0921\ (\text{heavy naphtha }^{\circ}\text{API})^2$$

$$\text{TOTAL COMBINED NAPHTHA, \#/min} = \frac{(\text{light naphtha in gas, SCFM})}{(379\ \text{SCF/\#mol})}(\text{M.W. of light naphtha}) + \frac{(\text{heavy naphtha in gas, SCFM})}{(379\ \text{SCF/\#mol})}(\text{M.W. of heavy naphtha})$$

$$\text{TOTAL COMBINED NAPHTHA, gal/hr} = \frac{(\text{total combined naphtha, \#/min})(60\ \text{min/hr})}{(\text{density of combined naphtha, \#/gal})}$$

$$\text{LIGHT NAPHTHA Gal/ton} = \frac{(\text{light naphtha in gas, SCFM})(\text{M.W. of light naphtha})}{(379\ \text{SCF/\# mol})(\text{light naphtha density, \#/gal})(\text{moist raw shale in, tph})}$$

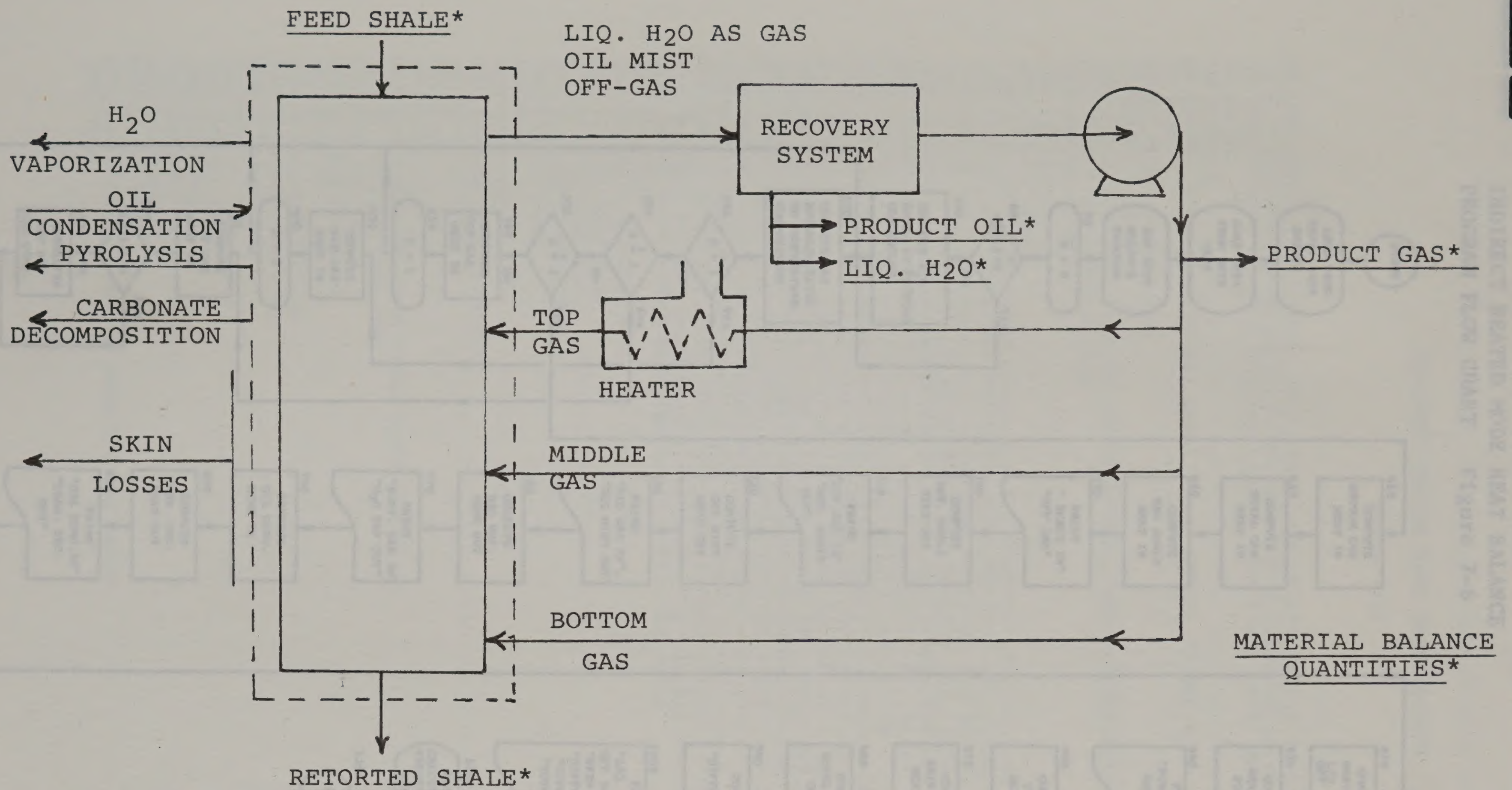
$$\text{HEAVY NAPHTHA Gal/ton} = \frac{(\text{heavy naphtha in gas, SCFM})(\text{M.W. of heavy naphtha})}{(379\ \text{SCF/\# mol})(\text{heavy naphtha density, \#/gal})(\text{moist raw shale in, tph})}$$

$$\text{VOL\% of F.A.} = \frac{(\text{dry oil, gph}) + (\text{total combined naphtha, gph})}{(\text{moist raw shale, tph})(\text{F.A. raw shale, gpt})}$$

Adjustments have also been made to the component & elemental balances to account for the differences inherent to the C5+ basis.

In Section 7.1 presented previously, the text captioned "Notes Applicable to Direct and Indirect Mode Material and Heat Balances," discusses some of the bases of calculations. Further explanation is presented in Table 7-18 in two parts.

Figure 7-5 shows the heat balance boundary and identifies the streams tabulated in the print out. Table 7-19 is a print out of input data, the material balance, and heat balance for Indirect Heated Mode Run SW-28, combined tests A-4.1 and A-4.2.



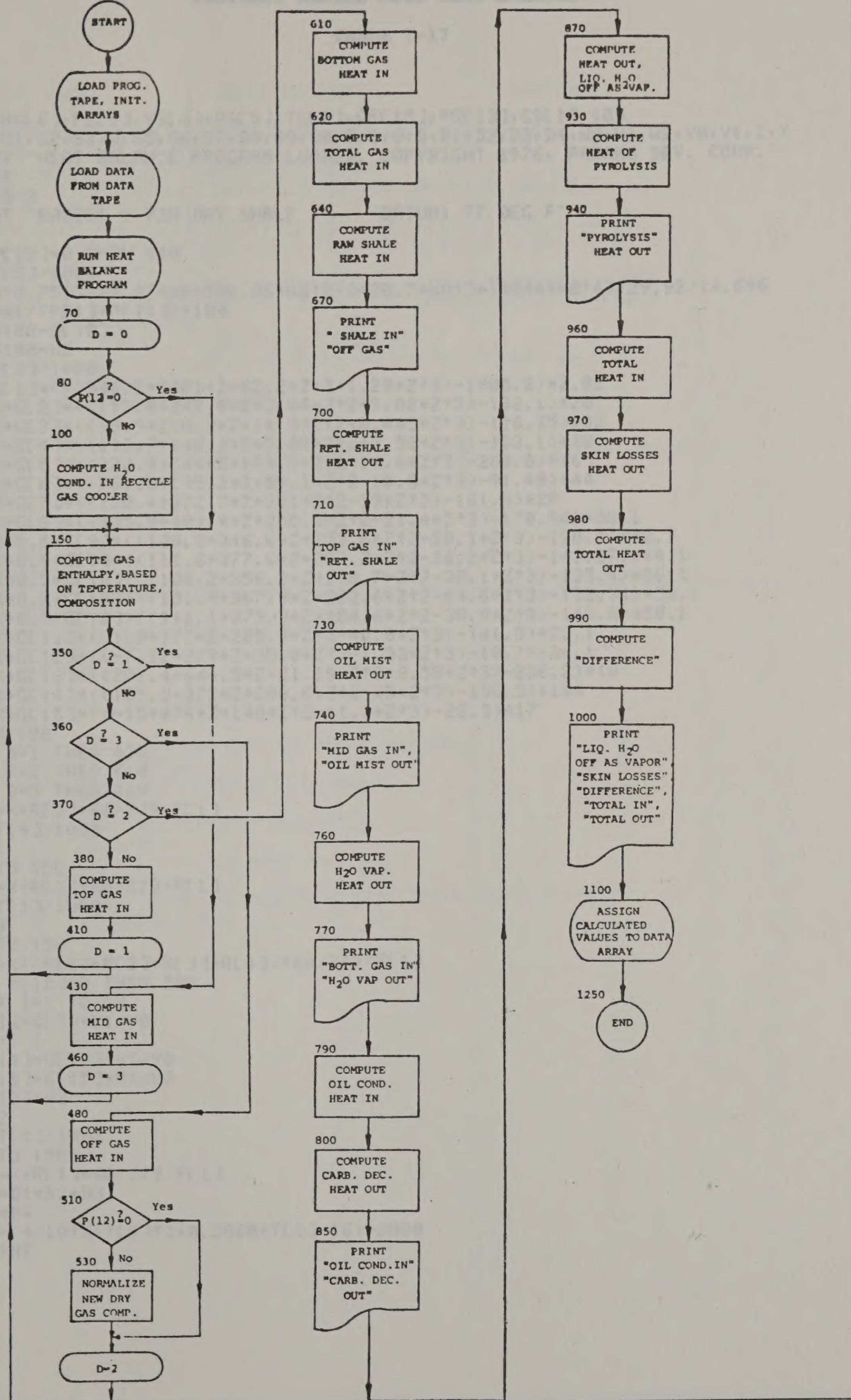
PARAHO INDIRECT HEATED RETORT

COMPUTER BALANCES

FIGURE 7.5

HEAT BALANCE BOUNDARY

INDIRECT HEATED MODE HEAT BALANCE PROGRAM FLOW CHART Figure 7-6



INDIRECT HEATED MODE HEAT BALANCE

TABLE 7-17

```
10 COM HS[6],FS[9],Y3[8],RS[5],TS[9],GS[15],PS[13],CS[10,10]
20 DIM S1,S2,S3,W,S5,S6,S7,S8,S9,S0,I,O,U,D,D1,D2,D3,D4,W0,W1,W2,V0,V1,Z,X
30 PRINT "HEAT BALANCE PROGRAM LOADED. COPYRIGHT 1976, PARAHO DEV. CORP."
40 PRINT
50 FIXED 3
60 PRINT "BASIS: 1 TON DRY SHALE        DATUM: 77 DEG F"
70 D=0
80 IF P[12]=0 THEN 140
90 W0=T[5]/1000
100 W1=(0.7513-29.27*W0+506.06*W0↑2-3420.7*W0↑3+14844*W0↑4)*29.92/14.696
110 W2=W1/(P[1]+P[11])*100
120 V0=100-G[13]
130 V1=100-W2
140 Z=T[3]/1000
150 X=G[1]*((1546.3+3401*Z+62.2*Z↑2+1.29*Z↑3)-1805.8)*2.02
160 X=X+G[2]*((113.8+247.8*Z+3.86*Z↑2+3.82*Z↑3)-133.1)*28
170 X=X+G[3]*((98.9+220.3*Z+14.3*Z↑2+0.445*Z↑3)-116.35)*32
180 X=X+G[4]*((113.7+248.3*Z+5.86*Z↑2+3.52*Z↑3)-133.1)*28
190 X=X+G[5]*((222.4+544*Z+169.2*Z↑2+14.6*Z↑3)-268.8)*16
200 X=X+G[6]*((76.15+195.2*Z+59.1*Z↑2-10.8*Z↑3)-91.48)*44
210 X=X+G[7]*((130.4+372.7*Z+201*Z↑2-19*Z↑3)-161.9)*28
220 X=X+G[8]*((135.9+409.4*Z+255.2*Z↑2-21.4*Z↑3)-170.86)*30.1
230 X=X+0.5*G[9]*((109.3+346.6*Z+233.6*Z↑2-28.1*Z↑3)-138.4)*42.1
240 X=X+0.5*G[9]*((111.6+377.6*Z+287.2*Z↑2-36.2*Z↑3)-143.27)*44.1
250 X=X+0.5*G[10]*((106.2+356.2*Z+258.7*Z↑2-38.1*Z↑3)-135.4)*56.1
260 X=X+0.2*G[10]*((101.9+367.9*Z+302.6*Z↑2-44.6*Z↑3)-132.34)*58.1
270 X=X+0.3*G[10]*((112.1+379.9*Z+284.6*Z↑2-38.9*Z↑3)-143.8)*58.1
280 X=X+G[11]*((110+377*Z+285.9*Z↑2-40.8*Z↑3)-141.3)*72.1
290 X=X+G[12]*((-7.12+229*Z+35.8*Z↑2-1.33*Z↑3)-10.7)*34.1
300 X=X+G[13]*((201.4+444.5*Z+21.19*Z↑2+8.58*Z↑3)-236.2)*18
310 X=X+G[14]*((105.3+372*Z+288.6*Z↑2-45*Z↑3)-136.3)*144
320 X=X+G[15]*((-15+474*Z+140*Z↑2-11.3*Z↑3)-22.3)*17
330 X=X/100
350 IF D=1 THEN 430
360 IF D=2 THEN 610
370 IF D=3 THEN 480
380 D1=X*R[3]*60/379/F[1]
390 Z=T[4]/1000
410 D=1
420 GOTO 150
430 D2=X*R[2]*60/379/F[1]
440 Z=T[1]/1000
460 D=3
470 GOTO 150
480 D4=X*(R[1]+R[2]+R[3]+R[4])*60/379/F[1]
510 IF P[12]=0 THEN 590
530 FOR I=1 TO 12
540 G[I]=G[I]*V1/V0
550 NEXT I
560 G[14]=G[14]*V1/V0
570 G[15]=G[15]*V1/V0
580 G[13]=W2
590 D=2
592 Z=T[5]/1000
600 GOTO 150
610 D3=X*R[1]*60/379/F[1]
620 S3=D1+D2+D3
630 S5=D4
640 S1=(4/10↑5*T[8]↑2+0.2068*T[6]-16)*2000
650 PRINT
```

INDIRECT HEATED MODE HEAT BALANCE (CONTD)

TABLE 7-17 (CONTD)

```
660 PRINT TAB5"            HEAT IN"TAB35"          HEAT OUT"
670 PRINT
680 FORMAT "SHALE IN",14X,F8.0,7X,"OFF GAS",15X,F8.0
690 WRITE (15,680)S1,S5
700 S6=0.2224*(T[6]-77)*2000*Y[1]/F[1]
710 FORMAT "TOP GAS IN",12X,F8.0,7X,"RET SH OUT",12X,F8.0
720 WRITE (15,710)D1,S6
730 S7=Y[6]*8.33*(141.5/(Y[8]+131.5))*(0.478*T[1]-36.8)/F[1]
740 FORMAT "MID GAS IN",12X,F8.0,7X,"OIL MIST OUT",10X,F8.0
750 WRITE (15,740)D2,S7
760 S8=(F[2]*1000/(100-F[2])+(F[5]-F[9])*1250/(100-F[9]))*2000
770 FORMAT "BOT GAS IN",12X,F8.0,7X,"H2O VAPORIZATION",6X,F8.0
780 WRITE (15,770)D3,S8
790 S2=Y[6]*8.33*141.5/(Y[8]+131.5)*70/F[1]
800 S9=2000/100*(F[7]*100/(100-F[9])-Y[3]*Y[1]/F[1])/44
810 IF S9<2.5 THEN 840
820 S9=(S9-2.5)*75096+2.5*58835
830 GOTO 850
840 S9=S9*58835
850 FORMAT "OIL CONDENSATION",6X,F8.0,7X,"CARBONATE DECOMP",6X,F8.0
860 WRITE (15,850)S2,S9
870 Z0=T[1]/1000
880 Z1=(T[1]+77)/2000
890 Z=Z0+Z1
900 Z2=Z0↑2+Z1↑2
910 Z3=Z0↑3+Z1↑3
920 S0=Y[7]*8.337*(0.4455+0.8846+0.0354*Z+0.054*Z2-0.0162*Z3)*(T[1]-77)/F[1]/3
930 X2=32*2000
940 FORMAT 37X,"PYROLYSIS",13X,F8.0
950 WRITE (15,940)X2
960 I=S1+S2+S3
970 L=10000
980 O=S0+S5+S6+S7+S8+S9+L+X2
990 U=I-O
1000 FORMAT 37X,"LIQ H2O OFF AS VAPOR",2X,F8.0
1010 WRITE (15,1000)S0
1020 FORMAT 37X,"SKIN LOSSES",11X,F8.0
1030 WRITE (15,1020)L
1040 FORMAT 37X,"DIFFERENCE",12X,F8.0
1050 WRITE (15,1040)U
1060 FORMAT 23X,"-------",30X,"-------"
1070 WRITE (15,1060)
1080 FORMAT 10X,"TOTAL IN",4X,F8.0,17X,"TOTAL OUT",3X,F8.0
1090 WRITE (15,1080)I,O+U
1100 C[5,1]=S1
1101 C[5,2]=S2
1110 C[5,3]=S3
1120 C[5,5]=S5
1130 C[5,6]=S6
1140 C[5,7]=S7
1150 C[5,8]=S8
1160 C[5,9]=S9
1170 C[5,10]=S0
1180 C[6,1]=I
1190 C[6,2]=O
1200 C[6,3]=U
1210 PRINT
1220 PRINT
1230 STANDARD
1240 FIND 3
1250 END
```

TABLE 7-18

BASIS: 1 TON DRY SHALE DATUM: 77°F

<u>HEAT BALANCE</u> (INDIRECT MODE)

HEAT IN:

Oil Condensation Btu/Ton = $\dfrac{\text{(Oil produced, gph) (Oil density,\#/gal) (70 Btu/lb)}}{\text{(dry raw shale, tph)}}$

Raw Shale In Btu/Ton = $\left[4 \times 10^{-5}(\text{temp. shale in,}^{o}\text{F})^{2} + 0.2068(\text{temp. shale in,}^{o}\text{F}) - 16\text{,Btu/\#}\right]$ (2000#/ton)

TOP GAS IN Btu/Ton = $\left[\sum (\text{vol\% of gas comp. i})\begin{pmatrix}\text{enthalpy of comp. i at top}\\ \text{dist. inlet temp, Btu/\#}\end{pmatrix}(\text{M.W. of comp.i})\right]\left[\dfrac{\text{(top gas, SCFM) (60 min/hr)}}{\text{(100) (379 SCF/\#mol) (dry raw shale,tph)}}\right]$

MID GAS IN Btu/Ton = $\left[\sum (\text{vol\% of gas comp. i})\begin{pmatrix}\text{enthalpy of comp. i at mid}\\ \text{dist. inlet temp, Btu\#}\end{pmatrix}(\text{M.W. of comp.i})\right]\left[\dfrac{\text{(mid gas, SCFM) (60 min/hr)}}{\text{(100) (379 SCF/\#mol) (dry raw shale, tph)}}\right]$

BOTTOM GAS IN Btu/Ton = $\left[\sum (\text{vol\% of gas* comp.i})\begin{pmatrix}\text{enthalpy of comp.i at bottom}\\ \text{gas inlet temp, Btu/\#}\end{pmatrix}(\text{M.W. of comp.i})\right]\left[\dfrac{\text{(bottom gas, SCFM) (60 min/hr)}}{\text{(100) (379 SCF/\#mol) (dry raw shale,tph)}}\right]$

*where the water content of the recycle gas is adjusted for condensation that occurs in the bottom gas cooler.

HEAT OUT:

RETORTED SHALE OUT btu/ton = $\dfrac{(0.2224\ \text{Btu/\#}^{o}\text{F})(\text{retorted shale temp} - 77,^{o}\text{F})(2000\text{\#/ton})(\text{retorted shale, tph})}{\text{Raw shale, tph}}$

OIL MIST OUT Btu/ton = $\dfrac{(\text{oil produced,gph})(\text{oil density \#/gal})\left[0.478(\text{off gas temp,}^{o}\text{F}) - 36.8\right]}{(\text{dry raw shale, tph})}$

Heat Balance (Indirect Heated Mode) Contd.

Table 7-18 (Contd)

PYROLYSIS OUT = (32 Btu/#)(2000 #/ton)
Btu/ton

SKIN LOSSES = 10,000 Btu/ton
Btu/ton

LIQUID WATER OUT AS VAPOR Btu/ton =

$$\frac{(\text{off gas temp} - 77)(\text{liquid } H_2O,\text{gph})(8.337\ \#/\text{gal})\left[1.3301 + 0.0354\left(\frac{TDIT}{1000}\right) + 0.054\left(\frac{TDIT}{1000}\right)^2 - 0.0162\left(\frac{TDIT}{1000}\right)^3\right]}{3(\text{dry raw shale, tph})}$$

Where TDIT is top distributor inlet temperature, ^{o}F

OFF GAS Btu/Ton =

$$\left[\sum (\text{vol\% of gas comp. i})\left(\begin{array}{l}\text{enthalpy of comp. i at off}\\ \text{gas temp, Btu/\#}\end{array}\right)(\text{M.W. of comp. i})\right]\left[\frac{(\text{off gas rate, SCFM})(60\ \text{min/hr})}{(100)(379\ \text{SCF/\# mol})(\text{dry raw shale in,tph})}\right]$$

H_2O VAPORIZATION Btu/ton =

$$(2000\#/\text{ton})\left[\frac{(\text{tylab moisture,wt\%})(1000\ \text{Btu/\#})}{(100 - \text{tylab moisture, wt\%})} + \frac{(\text{raw shale F.A. water, wt\%} - \text{lab moisture,wt\%})(1250\ \text{Btu/\#})}{(100 - \text{lab moisture, wt\%})}\right]$$

CARBONATE DECOMPOSITION =

$$\frac{(2000\ \#/\text{ton})}{(100)\left(44\ \frac{\#}{\#\ \text{mol}}\right)}\left[\frac{(\text{raw shale min.}CO_2,\ \text{wt\%})(100)}{(100 - \text{lab moisture, wt\%})} - \frac{(\text{retorted shale, tph})(\text{ret. shale min. }CO_2,\text{wt\%})}{(\text{raw shale, tph})}\right]$$

then if carbonate decomposition, measured as #mol/ton of CO_2, is less than or equal to 2.5, multiply amount liberated by 58,835 Btu/# mol as the heat of decomposition of M_gCO_3. It as assumed that all carbonate decomposition in excess of 2.5 # mol/ton production of CO_2 is liberated from the decomposition of $CaCO_3$, whose heat of decomposition is 75096 Btu/#mol.

Difference = $\sum$ Heat Inputs − $\sum$ Heat Outputs
Btu/ton

HEAT IN = shale in + top gas in + mid gas in + bottom gas in + oil condensation
Btu/Ton

HEAT OUT = off gas out + retorted shale out + oil mist out + H_2O vaporization + carbonate decomposition + pyrolysis + liquid H_2O out as vapor + skin losses + difference

TABLE 7-19

```
H(6)
UNIT 2    RUN 28    TEST 1000    MMDDYY 31976    HRS 36    0
F(9)
DRY SH,TPH 10.21    MOIST. % 1.23    FA,GPT 26.3    FA OIL,WT% 10.02
FA H2O 1.68    FA G+L 2.03    MIN CO2 17.7    ASH 67.98    LAB MOIST 0.58
Y(8)
RET SH,TPH 9.1  FA GPT 0.5  MIN CO2 19.47    ASH 76.68
H2O IN OIL,WT% 1.1  DRY OIL,GPH 247.5   H2O LIQ,GPH 36.6    API 20.2
R(5)
BTM GAS,SCFM 2034    MID 0    TOP 1792    PROD 91    S.G. 0.719
T(9)
OFF GAS,F 326  GAS BL DIS 214  TOP DIST 1299    MID DIST 214
BOT DIST 150  RET SH 336  PROD OIL 147  SHALE IN 40
GAS COND OUT 150
G(15),ALL MOL %
H2 17.72   N2 0.40    O2 0.00    CO 1.93    CH4 22.68   CO2 10.75
C2H4 8.98    C2H6 3.19    C3'S 1.61    C4'S 0.43    C5'S 0.02
H2S 1.99    H2O 28.82   OIL 0.62    NH3 0.86
P(13)
BARO 24.1    RAW %: C 16.16    H 1.7   N 0.45    RET %: C 8.37
H 0.33    N 0.34    OIL %: C 84.89    H 11.44    N 2.03    BOT PR 4.1
```

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BALANCES	IN	OUT	UNITS	FR.REC.
ASH	232.71	232.60	#/MIN	1.000
WATER	8.00	6.33	#/MIN	0.791
		5.08 L		
		1.25 V		
KEROGEN	43.27	45.89	#/MIN	1.061
		11.68 S		
		32.05 O		
		2.17 G		
ORG. CARBON	38.78	38.15	#/MIN	0.984
		9.27 S		
		27.21 O		
		1.67 G		
ORG. HYDROGEN	5.17	5.19	#/MIN	1.004
		1.00 S		
		3.67 O		
		0.53 G		
ORG. NITROGEN	1.54	1.71	#/MIN	1.111
O'ALL WEIGHT	344.57	345.46	#/MIN	1.003

91.64 VOL%FA   93.44 WT.%FA   2.53 % CARB DEC

HEAT BALANCE PROGRAM LOADED. COPYRIGHT 1976, PARAHO DEV. CORP.

BASIS: 1 TON DRY SHALE   DATUM: 77 DEG F

HEAT IN		HEAT OUT	
SHALE IN	-15328	OFF GAS	146097
TOP GAS IN	402104	RET SH OUT	102679
MID GAS IN	0	OIL MIST OUT	22419
BOT GAS IN	20853	H2O VAPORIZATION	52567
OIL CONDENSATION	13184	CARBONATE DECOMP	12034
		PYROLYSIS	64000
		LIQ H2O OFF AS VAPOR	3364
		SKIN LOSSES	10000
		DIFFERENCE	7654
	-------		-------
TOTAL IN	420813	TOTAL OUT	420813

APPENDIX

PILOT PLANT OPERATING SUMMARY

TABLE A-1

RUN NO.	PURPOSE	MODE	TESTS	START DATE	TIME	FINISH DATE	TIME	DAYS OPERATING TIME	% OPERATING TIME	SHALE RETORTED TONS	OIL PRODUCED GALLONS	REASON FOR OUTAGE
1-1	PRELIMINARY SHAKEDOWN	DIRECT	0	5/28/74	1325	5/31/74	1440	3.03	99.0			ELECTRICAL FAILURE
1-2	PRELIMINARY SHAKEDOWN	DIRECT	3	6/2/74	0925	6/6/74	1600	4.27	100.0	183.9	3829	PLANNED SHUT-DOWN
2-1	START UP TESTS	DIRECT	0	6/16/74	1117	6/19/74	1400	3.11	99.3	87.0	1497	ELECTRICAL FAILURE
3-1	START UP TESTS	DIRECT	0	6/25/74	1618	6/25/74	1700	.03	100.0			GRATE SETTING
3-2	START UP TESTS	DIRECT	0	6/25/74	2155	6/26/74	0425	.27	100.0			PROCESS UPSET
3-3	START UP TESTS	DIRECT	0	6/28/74	1950	6/29/74	1240	.73	100.0			LOSS OF COMBUSTION ZONE
3-4	START UP TESTS	DIRECT	0	6/29/74	1653	6/30/74	0400	.46	100.0	6.36	112	PROCESS UPSET
4-1	START UP TESTS	DIRECT	0	7/10/74	1317	7/10/74	1820	.21	100.0			LOSS OF COMBUSTION ZONE
4-2	START UP TESTS	DIRECT	0	7/11/74	1235	7/11/74	1800	.22	100.0			FAULTY START UP
4-3	START UP TESTS	DIRECT	0	7/12/74	1635	7/13/74	0150	1.39	57.3			ESP FAILURE
4-4	START UP TESTS	DIRECT	0	7/16/74	1235	7/17/74	0600	.72	100.0	20.4	392	FAULTY START UP
5	START UP TESTS & VAR. STUDY	DIRECT	5	7/24/74	1602	8/1/74	1602	8.00	91.4	129.3	2863	PLANNED SHUT-DOWN
6	MASS RATE TESTS	DIRECT	6	8/6/74	1500	8/15/74	1600	9.04	97.9	196.8	4767	PLANNED SHUT-DOWN
7	START UP TESTS FOR S.W.	DIRECT	0	10/6/74	1023	10/7/74	0515	.78	100.0	12.8	250	LOSS OF FEED
8-1	START UP TESTS	DIRECT	0	10/31/74	0837	10/31/74	0950	.05	100.0			LOSS OF COMBUSION ON START UP
8-2	START UP TESTS	DIRECT	0	10/31/74	1557	10/31/74	1718	.05	100.0			LOSS OF COMBUSTION ON START UP
8-3	START UP TESTS	DIRECT	0	11/1/74	1610	11/1/74	1730	.05	100.0			LOSS OF COMBUSTION ON START UP
8-4	START UP TESTS	DIRECT	0	11/2/74	1138	11/2/74	1307	.05	100.0			LOSS OF COMBUSTION ON START UP
8-5	START UP TESTS	DIRECT	0	11/2/74	1924	11/2/74	2058	.06	100.0			LOSS OF COMBUSTION ON START UP
8-6	START UP TESTS	DIRECT	0	11/3/74	1114	11/3/74	1138	.01	100.0			LOSS OF COMBUSTION ON START UP
8-7	START UP TESTS	DIRECT	0	11/3/74	1419	11/3/74	1649	.08	100.0			LOSS OF COMBUSTION ON START UP
8-8	START UP TESTS	DIRECT	0	11/4/74	1444	11/5/74	0520	.60	100.0	20.2	303	FAULTY START UP
9-1	START UP TESTS	DIRECT	0	11/19/74	1103	11/19/74	2100	.41	100.0			LOSS OF COMBUSTION ZONE
9-2	START UP TESTS	DIRECT	0	11/20/74	2046	11/20/74	2207	.06	100.0			LOSS OF COMBUSTION ZONE
9-3	MASS RATE TEST	DIRECT	4	11/21/74	0905	11/25/74	1100	4.08	97.0	117.2	2541	PLANNED SHUT-DOWN
10-1	MASS RATE TEST	DIRECT	0	12/7/74	0920	12/7/74	1928	.42	94.2			PROCESS UPSET
10-2	MASS RATE TEST	DIRECT	4	12-8-74	1313	12/12/74	1000	3.87	99.4	134.2	3362	PROCESS UPSET
11	PRELIMINARY SHAKEDOWN	INDIRECT	1	3/28/75	1407	4/2/75	0230	5.52	88.7	119.9	1067	LOSS OF PRESSURE CONTROL
12-1	PRELIMINARY SHAKEDOWN	INDIRECT	0	4/5/75	0856	4/7/75	1550	2.29	86.6			GAS LEAK AT DISTRIBUTOR
12-2	PRELIMINARY SHAKEDOWN	INDIRECT	0	4/11/75	1550	4/13/75	2315	2.34	81.8			DISCH. GRATE FAILURE
12-3	PRELIMINARY SHAKEDOWN	INDIRECT	0	4/15/75	1035	4/16/75	0038	.58	94.6			HEATER & TOP ROTARY SEAL FAILURE
12-4	PRELIMINARY SHAKEDOWN	INDIRECT	0	4/20/75	0945	4/20/75	1000	2.01	100.0	116.8	2664*	HEATER FAILURE
13-1	MASS RATE TEST	DIRECT	0	5/12/75	0330	5/15/75	0930	3.25	96.6			AIR BLOWER FAILURE
13-2	MASS RATE TEST	DIRECT	0	5/17/75	2247	5/23/75	1414	5.67	86.9			RECYCLE BLOWER FAILURE
13-3	VARIABLE STUDY	DIRECT	0	5/27/75	1743	6/4/75	0615	7.52	95.0	368.0	7851	LOSS OF COMBUSTION ZONE
14-1	START UP TESTS	INDIRECT	0	6/11/75	1726	6/13/75	0610	1.53	99.3			FAULTY PROCESS CONDITIONS
14-2	START UP TESTS	INDIRECT	0	6/14/75	1430	6/22/75	2100	8.27	96.4			FAULTY PROCESS CONDITIONS
14-3	START UP TESTS	INDIRECT	0	6/23/75	2243	6/25/75	2150	2.00	100.0			FAULTY PROCESS CONDITIONS
14-4	START UP TESTS	INDIRECT	0	6/27/75	1820	7/1/75	1300	3.76	94.8	266.6	5792	BLOWER LIMITATIONS & HEATER FAILURE

PILOT PLANT OPERATING SUMMARY

TABLE A-1 (CONT.)

RUN NO.	PURPOSE	MODE	TESTS	START DATE	TIME	FINISH DATE	TIME	DAYS OPERATING TIME	% OPERATING TIME	SHALE RETORTED TONS	OIL PRODUCED GALLONS	REASON FOR OUTAGE
15-1	HEATER SHAKEDOWN	INDIRECT	0	7/4/75	0440	7/5/75	0110	0.81	96.8			FAULTY PROCESS CONDITIONS
15-2	HEATER SHAKEDOWN	INDIRECT	0	7/6/75	0125	7/8/75	0430	2.13	95.8			FAULTY PROCESS CONDITIONS
15-3	HEATER SHAKEDOWN	DIRECT & INDIRECT	0	7/23/75	2047	8/8/75	1950	15.96	95.2			LOSS OF SHALE FEED EQUIPMENT
15-4	VARIABLE STUDY	DIRECT	0	8/13/75	1940	8/20/75	1540	6.83	99.8			PROCESS UPSET
15-5	VARIABLE STUDY	DIRECT	0	8/23/75	1120	8/23/75	2350	.05	100.0			RECYCLE BLOWER FAILURE
15-6	VARIABLE STUDY	DIRECT	0	8/26/75	1416	8/28/75	0400	1.57	84.7	580.2	13018	LOSS OF COMBUSTION ZONE
16	PURGE GAS PRODUCTION & VARIABLE STUDY	DIRECT	16	12/8/75	2140	2/23/76	2253	77.09	99.0	1833	42444	PLANNED SHUT-DOWN
17	PURGE GAS PRODUCTION	DIRECT	0	2/26/76	1811	3/1/76	2330	4.22	97.0	94.5	2064	LOSS OF COMBUSTION ZONE
18	PURGE GAS PRODUCTION	DIRECT	0	3/3/76	2021	3/31/76	0420	27.33	95.0	658.2	11308	BOTTOM ROTARY SEAL FAILURE
19	PURGE GAS PRODUCTION & VARIABLE STUDY	DIRECT	3	3/31/76	1137	4/12/76	1342	12.09	99.8	262.3	5318	PLANNED SHUT-DOWN

SEMI-WORKS OPERATING SUMMARY

TABLE B-1

RUN NO.	PURPOSE	MODE	TESTS	START DATE	TIME	FINISH DATE	TIME	DAYS OPERATING TIME	% OPERATING TIME	SHALE RETORTED TONS	OIL PRODUCED GALLONS	REASON FOR OUTAGE
1-1	PRELIMINARY SHAKEDOWN	DIRECT	0	8/27/74	1020	8/27/74	1400	.15	100.0			FAULTY START UP
1-2	PRELIMINARY SHAKEDOWN	DIRECT	0	9/5/74	1120	9/6/74	1545	1.18	100.0			GRATE FAILURE
1-3	PRELIMINARY SHAKEDOWN	DIRECT	0	9/18/74	0921	9/18/74	1332	.17	100.0			FAULTY START UP PROCEDURE
1-4	PRELIMINARY SHAKEDOWN	DIRECT	0	9/23/74	1358	9/24/74	0450	.62	100.0	188.6	3860	GRATE FAILURE
2-1	START UP TESTS	DIRECT	0	10/15/74	1300	10/16/74	1125	.93	100.0			E.S.P. FAILURE
2-2	START UP TESTS	DIRECT	0	10/21/74	1330	10/21/74	2240	.38	100.0	195.4	2109	E.S.P. FAILURE
3-1	START UP TESTS	DIRECT	0	11/12/74	1438	11/12/74	2130	.29	100.0			PROCESS UPSET
3-2	START UP TESTS	DIRECT	0	11/14/74	1017	11/16/74	0730	1.88	100.0	449.5	6800	OIL DRAIN PLUGGED
4-1	DEMONSTRATION RUN	DIRECT	0	11/26/74	0915	11/27/74	1201	1.12	100.0			PROCESS UPSET
4-2	DEMONSTRATION RUN	DIRECT	0	11/30/74	1005	11/30/74	2330	.56	100.0			LOSS OF COMBUSTION ZONE
4-3	DEMONSTRATION RUN	DIRECT	0	12/2/74	1238	12/4/74	0945	.88	100.0	565.7	11190	PROCESS UPSET - FINES IN RAW SHALE
5-1	DEMONSTRATION RUN	DIRECT	0	12/12/74	2059	12/13/74	0213	.22	100.0			PROCESS UPSET
5-2	DEMONSTRATION RUN	DIRECT	0	12/14/74	0958	12/15/74	2000	1.42	99.3			E.S.P. FAILURE
5-3	DEMONSTRATION RUN	DIRECT	4	12/22/74	1336	1/1/75	0330	9.58	90.0	2367.8	45528	PROCESS UPSET - FINES IN RAW SHALE
6-1	DEMONSTRATION RUN	DIRECT	0	1/9/75	1257	1/10/75	0721	.77	100.0			LOSS OF COMBUSTION ZONE
6-2	DEMONSTRATION RUN	DIRECT	0	1/13/75	1246	1/14/75	0200	.55	100.0	217.0	4575	LOSS OF COMBUSTION ZONE
7	DEMONSTRATION RUN	DIRECT	32	1/17/75	0940	3/14/75	0940	56.0	88.3	12159	280124	PLANNED SHUTDOWN
8-1	REPEATABILITY TEST	DIRECT	0	4/25/75	2205	4/26/75	0500	.29	100.0			PROCESS UPSET
8-2	REPEATABILITY TEST	DIRECT	0	4/30/75	1650	5/3/75	0220	2.40	76.5			LOSS OF COMBUSTION ZONE
8-3	REPEATABILITY TEST	DIRECT	7	5/4/75	0825	5/16/75	1614	12.33	97.1	3785.7	87460	AIR-GAS BLOCKAGE TO MID. DIST.
9	MASS RATE TEST	DIRECT	1	5/24/75	0045	6/4/75	0820	10.31	91.1	2910.2	62298	RECYCLE BLOWER MOTOR FAILURE
10-1	PRELIMINARY SHAKEDOWN	INDIRECT	0	6/22/75	1518	6/22/75	2145	.27	78.2			LOSS OF RETORT PRESSURE CONTROL
10-2	PRELIMINARY SHAKEDOWN	INDIRECT	0	7/9/75	2225	7/13/75	1925	3.87	93.5			FAULTY PROCESS CONDITIONS
10-3	PRELIMINARY SHAKEDOWN	INDIRECT	0	7/19/75	2055	7/23/75	0600	3.38	97.6			FAULTY PROCESS CONDITIONS
10-4	PRELIMINARY SHAKEDOWN	INDIRECT	5	7/29/75	1110	8/6/75	0730	7.85	99.4	3631.8	54736	FAULTY PROCESS CONDITIONS
11-1	MASS RATE TEST	DIRECT	0	8/12/75	1545	8/14/75	0845	2.71	100.0			LOSS OF COMBUSTION ZONE
11-2	MASS RATE TEST	DIRECT	1	8/15/75	1435	8/24/75	0328	8.95	97.9			LOSS OF COMBUSTION ZONE
11-3	MASS RATE TEST	DIRECT	0	8/25/75	1455	8/27/75	2400	2.38	95.8	3304.1	66963	LOSS OF COMBUSTION ZONE
12	REPRODUCIBILITY	DIRECT	0	9/29/75	1015	10/1/75	0030	1.59	100.0	367.9	9374	FAULTY OPERATION CONDITIONS
13	REPRODUCIBILITY	DIRECT	0	10/2/75	1145	10/3/75	1705	1.22	100.0	244.9	4719	FAULTY OPERATION CONDITIONS
14	REPRODUCIBILITY	DIRECT	0	10/5/75	0330	10/5/75	0700	.15	100.0	15.7	50	FAULTY START UP
15	REPRODUCIBILITY	DIRECT	0	10/5/75	1841	10/7/75	1800	1.97	99.5	472.8	10296	FAULTY OPERATION CONDITIONS
16	REPRODUCIBILITY	DIRECT	0	10/8/75	2255	10/13/75	0900	4.42	98.0	1226.5	23573	FAULTY OPERATION CONDITIONS
17-1	REPRODUCIBILITY	DIRECT	0	10/16/75	0908	10/16/75	1330	.18	100.0			FAULTY START UP
17-2	REPRODUCIBILITY	DIRECT	0	10/16/75	2029	10/17/75	0234	.25	100.0			FAULTY START UP
17-3	REPRODUCIBILITY	DIRECT	0	10/18/75	1136	10/18/75	2300	.48	100.0			FAULTY START UP
17-4	REPRODUCIBILITY	DIRECT	3	10/19/75	1106	10/24/75	0615	4.80	100.0	1206.1	27110	PROCESS UPSET - FINES IN RAW SHALE
18	DEMONSTRATION RUN	DIRECT	0	10/25/75	0047	10/25/75	2200	.88	100.0	148.2	3509	FAULTY OPERATION CONDITIONS
19-1	DEMONSTRATION RUN	DIRECT	0	10/27/75	0012	10/27/75	0310	.12	100.0			FAULTY START UP
19-2	DEMONSTRATION RUN	DIRECT	2	10/28/75	1030	11/6/75	1950	4.39	100.0			PROCESS UPSET - FINES IN RAW SHALE
19-3	DEMONSTRATION RUN	DIRECT	0	11/2/75	0639	11/3/75	0915	1.11	100.0	1262.8	29438	FAULTY START UP
20	DEMONSTRATION RUN	DIRECT	20	11/4/75	2145	11/30/75	1140	25.58	99.7	6771	167356	LOSS OF COMBUSTION ZONE
21	START UP TEST	INDIRECT	1	12/10/75	1640	12/15/75	0315	4.42	94.6	813.4	12870	LOSS OF RETORT PRESSURE CONTROL

SEMI-WORKS OPERATING SUMMARY

TABLE B-I (CONT.)

RUN NO.	PURPOSE	MODE	TESTS	START DATE	TIME	FINISH DATE	TIME	DAYS OPERATING TIME	% OPERATING TIME	SHALE RETORTED TONS	OIL PRODUCED GALLONS	REASON FOR OUTAGE
22	DEVELOP OPR. PROCESS	INDIRECT	2	12/18/75	1530	12/21/75	2300	3.31	99.1	548.0	12360	BROKEN DISTRIBUTOR LINE
23	DEMONSTRATION RUN	INDIRECT	16	1/10/76	0800	2/10/76	1321	31.18	96.6	6650.0	164997	OFF-GAS MANIFOLD PLUGGED
24	THERMAL EFF.	INDIRECT	0	2/13/76	0900	2/15/76	0520	1.85	99.7	339.0	6897	PROCESS UPSET
25	THERMAL EFF.	INDIRECT	0	2/18/76	1815	2/22/76	2145	4.15	100.0	786.0	13984	PROCESS UPSET
26	THERMAL EFF.	INDIRECT	0	2/28/76	0330	3/2/76	1810	3.15	97.0	647.0	13215	POWER FAILURE
27	THERMAL EFF.	INDIRECT	0	3/6/76	0830	3/9/76	0835	3.08	72.0	214.0	4152	GRATE FAILURE
28	THERMAL EFF.	INDIRECT	9	3/10/76	1335	3/23/76	0510	11.13	88.0	2340.0	55330	PROCESS UPSET
29	DEV. OPR. PROCEDURE	COMBINATION	2	3/25/76	1700	3/29/76	2330	3.28	100.0	596.7	11260	GRATE FAILURE
30	THERMAL EFF.	COMBINATION	0	3/30/76	1448	4/1/76	0900	1.76	67.6	172.0	2220	PROCESS UPSET
31	CONFIRMATION TEST	INDIRECT & COMBINATION	3	4/2/76	0620	4/9/76	1404	7.32	100.0	1770.0	46420	PLANNED SHUTDOWN

APPENDIX C

Run Evaluations and Equipment Changes

Run No.	Process Operated	Start Date	Key Results	Pre-Run Equipment Modifications
PP-	Cold Flow Test	4/9/74	Particle residence time in the retort is independent of radial position.	None
PP-	Cold Flow Test	5/8/74	Particle residence time in the retort in independent of particle size.	None
PP-1	Direct Heated	5/28/74	Initial air and gas rates for process operability were established. Momentary power outages plagued run. Three test periods obtained. Planned shutdown.	None
PP-2	Direct Heated	6/16/74	The importance of maintaing plug solids flow in the retort was demonstrated. Grate misallignment and inadequate feed screening caused carryover of dust to the precipitator. Problems described above and a power failure resulted in a shut-down.	None
PP-3	Direct Heated	6/25/76	Variations in fire-off procedures were investigated. Four unsuccessful fireoffs were made. Equilibrium conditions were never obtained.	Re-centered grate pusher bar.
PP-4	Direct Heated	7/10/74	The ability to place the retort in standby and restart several hours later was demonstrated. It was concluded that the bed height above the top air/gas distributor was too great, causing refluxing and consequent bridging. Equilibrium conditions were not obtained.	None

Run No.	Process Operated	Start Date	Key Results	Pre-Run Equipment Modifications
PP-5	Direct Heated	7/24/76	Five equilibrium test periods were obtained. Three standbys were required for equipment failure and power outages. Bridging occurred during the run, but operation was continued as scheduled.	The bed height was lowered by one foot to prevent refluxing.
PP-6	Direct Heated	6/6/74	Five equilibrium test periods were obtained at mass rates exceeding 400 #/hr/ft^2. Bridging occurred during run, but did not stop operation.	None
PP-7	Direct Heated	10/6/74	Equilibrium conditions were not attained. Problems were encountered with shale feed rate control causing fluctuations in bed temperatures.	None
PP-8	Direct Heated	10/31/74	Various start-up procedures were investigated. Eight fire-offs were made, with six resulting in loss of fire. The eighth fire-off failed due to fluctuations in shale feed rate similar to PP-7.	None
PP-9	Direct Heated	11/19/74	Four equilibrium test periods were obtained at mass rates up to 633 #/hr/ft^2. Start-up success was improved by using signal flares rather than diesel soaked blocks to ignite a fire.	Bed height was lowered for start-up only to minimize refluxing conditions.
PP-10	Direct Heated	12/7/74	Four equilibrium test periods were obtained at higher mass rates to 640 #/hr/ft^2.	None

Run No.	Process Operated	Start Date	Key Results	Pre-Run Equipment Modifications
PP-11	Indirect Heated	3/27/75	Initial characteristics of the Indirect heated process were determined. A stable operating period was obtained. Erratic retort pressure control caused air in leakage and undersirable combustion. Complete retorting was not attained.	A double rotary seal was installed to minimize gas losses. Orifice holes were enlarged to accommodate higher gas rates.
PP-12	Indirect Heated	4/5/75	Further definition of Indirect heated process. Four start-up attempts were made. Continued operation was handicapped by poor pressure control, grate stoppages, gas leaks, and heater problems.	A smaller product gas control valve was installed for improved pressure control. Permanent drain lines were installed at low point collection points.
PP-13	Direct Heated	5/12/75	Considerable success was realized in putting the retort back on line after standbys up to 7.6 hours in length. Problems with auxiliary equipment interfered with establishing equilibrium throughout run.	Product gas control valve changed back to direct mode size. Bed height increased.
PP-14	Indirect Heated	6/11/76	Experience was gained in start-up procedures for Indirect heated operation by transition from direct heated operation. Density product gas caused blower operation problems - difficult to maintain. Design gas to shale ratios caused refluxing during all operation. Run terminated by heater failure.	An oil coalescer assembly upstream of the ESP was installed to lower the mist loading and stabilize the electrostatic precipitator operation.
PP-15	Indirect and Direct Heated	7/4/75	Several stand-bys were required for mechanical repairs preventing equilibrium conditions from being established. The recycle gas heaters were inoperable after the first three start-up attemps. Operation was continued as direct heated retort.	An additional suction stage was installed on the recycle gas blower to improve operation with light gas.

Run No.	Process Operated	Start Date	Key Results	Pre-Run Equipment Modifications
PP-16	Direct Heated	12/8/75	This run represents the longest period of continuous operation thus far achieved. Product gas from the Pilot Plant was used as an emergency source of purge gas for Indirect mode operation in the semi-works. A total of 16 equilibrium test periods were obtained with successful duplication of test conditions established in semi-works run SW-20. A minimum of operator attention was required. Stand-bys were required occasionally for the minor equipment repairs. Following a stand-by to clean the middle distributor orifices excessive wet fines in the raw shale led to a decision to shutdown.	Bed height decreased.
PP-17	Direct Heated	2/26/76	Start-up procedure of PP-16 was successfully duplicated. Drive chain broke on bottom rotary seal necessitating a stand-by. Return to operating conditions after standby was unsuccessful.	None
PP-18	Direct Heated	3/3/76	Fire-off successful. Operation was regained from three standbys, one of 18.1 hours duration. Operation was primarily intended for an emergency supply of purge gas to the semi-works in indirect operation. Mechanical problems required four standbys. Shutdown was caused by shearing of the bottom rotary seal hub.	None
PP-19	Direct Heated	3/31/76	Three equilibrium test periods were obtained while running richer than normal shale (32 gpt). Parametric studies of air split to the top and middle distributors were performed. One standby was required for hub repair on the bottom rotary seal.	None

Run No.	Process Operated	Start Date	Key Results	Pre-Run Equipment Modifications
SW-	Cold Flow Test	8/23/74	Particle resident time was not affected by size. Particles near the walls are slower in descent than those in the center. Particles near the flat side walls were 8% slower than those in the remainder of the bed. There was not a significant difference in residence time between the four quadrants of the retort.	None
SW-1	Direct Heated	8/27/74	An initial equipment shakedown was performed. Four start-up procedures were investigated. Damage to the thermocouple probe was evident in the first three start-up attempts from overheating. Hydraulic system failures on grate mechanism ended two start-up trials.	Additional propane capacity was added to supply fire-off requirements. Insulation was added to the thermocouple junction box for protection. A new thermocouple probe was required.
SW-2	Direct Heated	10/15/74	The second start-up was satisfactory until problems were encountered with the precipitator. Partial bridging and pluggage of the off-gas collectors ended start-up one. The second start-up was terminated by a short in the electrostatic precipitator.	Hydraulic seals on the grate cylinders were replaced with high temperature resistant material. Other modifications to the grate cylinders were made to prevent heat and dust problems. Grate contour changes made to correct shale flow pattern.
SW-3	Direct Heated	11/12/74	Start-up procedures were further developed. Fines and dust carry-over plugged off-gas collectors and prevented efficient flow of oil from the precipitator.	Extensive maintenance was performed on the electrostatic precipitator. Grate hydraulic cylinders were relocated to prevent dust and heat contamination of the seals.
SW-4	Direct Heated	11/26/74	Start-up procedures were further developed. Unsuccessful start-ups were attributed to excessive fines feed to the retort.	None

Run No.	Process Operated	Start Date	Key Results	Pre-Run Equipment Modifications
SW-5	Direct Heated	12/12/74	The third start-up ran for over nine days and four equilibrium test periods were obtained. Leaner shale was used on the third start-up. The start-up procedure developed for PP-9 and PP-10 were adapted to the Semi-Works. The final shutdown was attributed to excessive fines fed to the retort.	The precipitator was modified by installation of sludge removal pots. Flushing oil was provided for the bottom of the precipitator to remove sludge.
SW-6	Direct Heated	1/9/75	Start-up procedures were further investigated and modified.	The 10-inch top distributors were replaced with 6-inch diameter to improve shale flow. A drain system on the recycle gas lines was installed to prevent oil build-up at the orifice plates.
SW-7	Direct Heated	1/17/75	This run represented 56 days of operation without the need to empty the retort and fire-off again. A total of 32 equilibrium test periods were obtained. Considerable success was realized in restarting after lengthy stand-bys. Stand-bys were required for cleaning of the off-gas collectors, external removal of bridged material, and mechanical failure and checks. Oil rundown lines required occasional cleaning.	Rodding ports were installed on the side of the retort above the top distributor to provide a means to dislodge bridged material externally.
SW-8	Direct Heated	4/26/75	Seven test periods were obtained during the third start-up with no evidence of bridging. Coke build-up in the middle air/gas distributors terminated the third run.	A polishing screen was installed to remove fines produced at various transfer points and in the storage bins.
SW-9	Direct Heated	5/24/75	Mass rates as high as 625 $\#/hr/ft^2$ were attained. Start-up was accomplished with lean shale. Stand-bys were required for mechanical equipment repairs. Mechanical failure of the recycle blower motor required shutdown.	None

Run No.	Process Operated	Start Date	Key Results	Pre-Run Equipment Modifications
SW-10	Indirect Heated	6/22/75	Various start-up procedures were investigated combining direct/ indirect operation.	A coalescer system was installed to relieve oil mist loading to the precipitator. Stainless steel 10-inch gas distributors were installed with large orifice hole openings. A second rotary seal was added at the bottom of the retort. Provision was made to use the 300 BHP blower while the 700 was under repair. Different bed height adjustments were tried.
SW-11	Direct Heated	8/12/75	Experience was gained in higher mass rate operation. The loss of bed temperature measurements in the combustion zone resulted in loss of control locations and consequent shutdown of each of the three start-up attempts.	None
SW-12	Direct Heated	9/29/75	A shakedown of new equipment and modifications performed during the turnaround was accomplished.	A major turnaround was undertaken for equipment cleanup, repair and modification as follows: Rotary solids distributor was lengthed and off-gas collectors removed;new temperature and pressure probe installed; 6-inch diameter air/gas distributor replaced 10-inch. Orifice holes in top air-gas distributor were reduced in size for better distribution.
SW-13	Direct Heated	10/2/75	Operational problems were attributed to too great a bed height above the top air/gas distributor. Refluxing conditions resulted.	None

Run No.	Process Opearting	Start Date	Key Results	Pre-Run Equipment Modifications
SW-14	Direct Heated	10/5/75	A larger top size on the raw shale feed was tried to compensate for too much bed height. A portion of the combustion zone was lost shortly after fire-off requiring shutdown.	None
SW-15	Direct Heated	10/5/75	Larger top size shale was tried again with results shown that retorting of the larger particles was complete.	None
SW-16	Direct Heated	10/8/75	An investigation of larger top size feed continued. Restriction of flow through the middle air/gas distributor and a partial bridge forced a shutdown.	None
SW-17	Direct Heated	10/16/75	Equilibrium was attained after the fourth start-up, allowing test period calculation. Failures of the first three start-ups were attributed to plugged distributor piping and excessive fines in feed for the fourth start-up.	The off-gas collectors were reinstalled to lower the bed height. An on-line gas chromatograph was installed.
SW-18	Direct Heated	10/25/75	Further success was gained in the start-up procedure.	None
SW-19	Direct Heated	10/27/75	Operation after start-up two was stable enough to allow test period calculation. Increasing orifice sizes in the top distributor was significant on operations.	Orifice holes in the top air/gas distributors were enlarged to that size used in SW-10. Smaller holes existed during SW-12-18.
SW-20	Direct Heated	11/4/75	High oil recovery and trouble free operation were demonstrated for nearly 26 days. Consecutive test periods were obtained at identical operating conditions. Special tests were performed to determine basic design data. Brief power failure interrupted run requiring stand-by occasionally.	None

Run No.	Process Operated	Start Date	Key Results	Pre-Run Equipment Modifications
SW-21	Indirect Heated	12/10/75	Start-up procedure for the Indirect mode was established. Moisture content in the recycle gas was controlled by cooling with the coalescer. Hot gas was injected only at the top distributor. Continuous problems were experienced with maintaining heater firing. Problems were encountered with holding retort positive pressure.	A packed section in the coalescer, with oil circulation system for cooling the off-gas and condensing water was installed. Stainless steel distributors reinstalled with larger orifice holes. Lowered bed height.
SW-22	Indirect Heated	12/18/75	Further experience was gained in the Indirect operations. Incomplete retorting was experienced. Retort pressure control continued to be a problem. The retort was shutdown after an ignition occurred in the top gas line as a result of air being drawn into the retort during a negative pressure condition.	Further improvement was made in heater operation by various modifications. Six vane rotary seal replaced four vane in the retort top to minimize gas leakage.
SW-23	Indirect Heated	1/10/76	This run demonstrated operability of the indirect heated process. Considerable progress in improving thermal efficiency was made through the run. Heater outages were experienced frequently.	Heater repairs were performed as necessary. An air filter was installed on the primary air blower of the heater to prevent dust intake. Orifice holes in the bottom gas distributor were reduced for lower rates. A stand-by was taken during the run to install the bottom gas cooler.
SW-24	Indirect Heated	2/13/76	Heater problems affected process conditions.	Oil recovery system was modified for combined rundown of oil production.

Run No.	Process Operated	Start Date	Key Results	Pre-Run Equipment Modifications
SW-25	Indirect Heated	2/18/76	Particle agglomeration and pluggage of the off-gas piping required shutdown.	Repair of recycle gas heater.
SW-26	Indirect Heated	2/28/76	Special water samples were taken. Bed restrictions and pluggage of off-gas piping caused unstable operation. These plus a power outage necessitated a shutdown.	Number of orifice holes in the bottom gas distributor were increased to handle greater gas rates. Orifice holes in the top gas distributor were enlarged to reduce shale abrasion.
SW-27	Indirect Heated	3/6/76	Leakage in the recycle gas heater delayed start-up. Grate electrical problems resulted in bridging which terminated operations shortly after start-up.	An increase in bed height was made to prevent refluxing and consequent bridging. Modifications were made to the blower to prevent gas leakage.
SW-28	Indirect Heated	3/12/76	Several equilibrium test periods were obtained at conditions of high thermal efficiency. Oil viscosities were lower than normal. During a transition to higher thermal efficiency, bed pressure drop requiring shutdown.	None
SW-29	Combination Mode	3/25/76	Initial results of the combination heated process were obtained. Equilibrium test periods were derived. Discharge grate control malfunctioned causing loss of shale discharge.	None
SW-30	Combination Mode	3/31/76	Start-up was unsuccessful.	None
SW-31	Combination and Indirect Heated	4/2/76	Oil viscosities were particularly lower than previous indirect operation. Indirect operation was made to duplicate past operating results and conditions. This run was hindered by severe leakage in the recycle gas heater. Top pressure was difficult to control positive. Retort was shutdown as scheduled to complete project program.	None

APPENDIX D

TEST DATA

The test data tabulations in this section account for only those periods of retort operation that have been used to calculate complete operational and product data. A complete accounting of all operational time will be found in Appendix Section A for the Pilot Plant and Section B for the Semi-Works.

BASIS

The technique of obtaining laboratory and operating data and methods of processing this data have improved throughout this project. A common basis was chosen for presenting the data from all test periods for each mode of operation. Average values were calculated from most recent and reliable data. These values were used for the earlier runs where such information was not previously available or was considered to be unreliable. These values and the runs in which they were used are shown on Table D-1.

A light naphtha content of 0.62 Vol% in the gas stream for Indirect Heated operations was averaged from data collected during Semi-Works Run SW-23 and SW-28. This value was used for all Indirect Heated Mode data presented.

Retorted shale rates were calculated using an ash balance for those periods showing a deviation of more than ± 1% from measured values.

The column shown as Hot Gas for the Indirect Heated data reflects the heat content of the hot gas entering the top distributors as calculated from the 77°F Datum.

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TEST DATA VALUES

TABLE D - 1

Item	Value	Plant	From Run	To Run
Raw Shale Moisture Wt%	1.00	Pilot Plant	PP-1	PP-16
Raw Shale Moisture Wt%	1.00	Semi-Works	SW-5	SW-7(PC-1)
Raw Shale Lab Moist. Wt%	0.66	Pilot Plant	PP-1	PP-16
Raw Shale Lab Moist. Wt%	0.66	Semi-Works	SW-5	SW-20
Raw Shale Wt% C	17.09	Pilot Plant	PP-1	PP-16
Raw Shale Wt% C	17.09	Semi-Works	SW-5	SW-7
Raw Shale Wt% H	1.85	Pilot Plant	PP-1	PP-16
Raw Shale Wt% H	1.85	Semi-Works	SW-5	SW-7
Raw Shale Wt% N	0.51	Pilot Plant	PP-1	PP-16
Raw Shale Wt% N	0.51	Semi-Works	SW-5	SW-7
Manometer Fluid No. 1	1.07	Pilot Plant	PP-9	PP-16
Manometer Fluid No. 1	1.07	Semi-Works	SW-5	SW-20
Run Down Tank Gal/In.	29.65	Semi-Works	SW-5	SW-20
Cooling Water Gal/Min	17	Pilot Plant	PP-1	PP-9
Cooling Water Δ Temp, $^{\circ}$F	20	Pilot Plant	PP-1	PP-9
Cooling Water, Gal/Min	80	Semi-Works	SW-5	SW-7
Cooling Water Δ Temp $^{\circ}$F	20	Semi-Works	SW-5	SW-7
Retorted Shale Wt% C	6.24	Pilot Plant	PP-1	PP-16
Retorted Shale Wt% C	6.24	Semi-Works	SW-5	SW-7
Retorted Shale Wt% H	0.16	Pilot Plant	PP-1	PP-16
Retorted Shale Wt% H	0.16	Semi-Works	SW-5	SW-7
Retorted Shale Wt% N	0.20	Pilot Plant	PP-1	PP-16
Retorted Shale Wt% N	0.20	Semi-Works	SW-5	SW-7
Oil Wt% C	84.65	Pilot Plant	PP-1	PP-19
Oil Wt% C	84.65	Semi-Works	SW-5	SW-7
Oil Wt% H	11.49	Pilot Plant	PP-1	PP-19
Oil Wt% H	11.49	Semi-Works	SW-5	SW-7
Oil Wt% N	2.02	Pilot Plant	PP-1	PP-19
Oil Wt% N	2.02	Semi-Works	SW-5	SW-7
Product Gas (Wet) Vol% C_5+	0.34	Pilot Plant	PP-1	PP-19
Product Gas (Wet) Vol% C_5+	0.34	Semi-Works	SW-5	SW-21
Product Gas (Wet) Vol% C_5+	0.62	Semi-Works	SW-21	SW-31
Product Gas (Wet) Tot. Anal. SW-20'As		Pilot Plant	PP-1	PP-9
Product Gas (Wet) Vol% H_2O	20	Pilot Plant	PP-1	PP-19
Product Gas (Wet) Vol% H2O	20	Semi-Works	SW-5	SW-17

TEST DATA FROM PILOT PLANT — DIRECT HEATED

TABLE D-2

GENERAL: RUN NUMBER / TEST NUMBER	PP-1 A	PP-1 B	PP-1 C	PP-5 A	PP-5 B	PP-5 C	PP-5 D	PP-5 E	PP-6 A	PP-6 B	PP-6 C	PP-6 D	PP-6 G-1
DATE	5/29/74	6/4/74	6/6/74	7/25/74	7/26/74	7/27/74	7/28/74	7/30/74	8/10/74	8/11/74	8/12/74	8/13/74	8/14/74
START TIME	0800	0800	0800	2400	1600	1600	1600	0800	0800	0800	0800	0800	0500
LENGTH OF TEST hrs.	48	24	5	16	16	16	24	8	16	16	16	11	8
RATES AND QUANTITIES:													
TOP DISTRIBUTOR GAS SCF/T	1277	1350	1359	2960	3099	2549	1478	1527	1552	1582	1453	1449	1324
MID DISTRIBUTOR GAS SCF/T	1393	1512	1620	942	6620	2230	1478	1527	1851	1808	1688	1705	1785
BTM DISTRIBUTOR GAS SCF/T	10793	12043	11812	13453	6620	12637	9829	10944	13313	13898	12703	12230	13244
TOTAL GAS SCF/T	13463	14905	14791	17355	16339	17416	12785	13998	16716	17288	15844	15384	16353
TOP DISTRIBUTOR AIR SCF/T	3191	3294	3449	6726	7183	5310	3276	3245	3881	4124	3797	3622	3628
MID DISTRIBUTOR AIR SCF/T	1509	1242	1098	0	141	1062	964	1336	1910	1921	1781	1705	1843
BTM DISTRIBUTOR AIR SCF/T	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL AIR SCF/T	4700	4536	4547	6726	7324	6372	4240	4581	5791	6045	5578	5327	5471
SHALE THROUGHPUT lb/hr/ft^2	420	451	466	181	173	229	379	383	408	431	520	572	423
TEMPERATURES:													
PRODUCT OIL °F	126	133	129	140	133	139	125	127	153	161	139	138	133
RETORTED SHALE OUT °F	305	339	335	302	352	374	404	367	358	352	444	462	416
RAW SHALE IN °F	80	82	67	113	105	103	89	90	86	67	82	79	87
RECYCLE GAS IN °F	239	247	244	250	246	254	239	242	260	272	254	226	246
OFF-GAS °F	150	150	150	197	178	195	135	145	197	200	160	146	154
AIR IN °F	233	229	216	250	250	247	247	247	245	240	232	235	233
YIELDS:													
OIL COLLECTED wt%F.A.	83.4	91.3	126.4	89.2	95.4	93.2	92.6	82.8	84.6	88.6	86.3	90.1	96.1
PRODUCT GAS (WET) SCF/T	6383	6859	6429	10897	11127	9770	5717	5917	8119	8079	7359	6690	6622
RETORTED SHALE wt%R.S.	84	84	86	74	75	76	85	83	81	80	82	82	83
LIQUID WATER lb/ton	8.87	0.54	9.45	5.61	5.87	5.76	5.89	5.22	0.17	0	0.72	0.77	0.56
ASH BALANCE wt%	101	100	100	100	100	100	100	99	100	100	100	100	100
ATM N_2 BALANCE wt%	86	96	90	102	96	97	85	81	89	85	84	80	77
WATER BALANCE wt%	77	78	73	72	69	73	87	67	68	58	68	56	57
KEROGEN BALANCE wt%	99	106	166	92	105	98	101	91	100	96	99	102	106
ORG. CARBON BALANCE wt%	86	90	115	102	107	100	89	82	94	92	92	91	96
TOT. H_2 BALANCE wt%	89	91	115	110	115	107	91	85	97	95	94	92	96
ORG. N_2 BALANCE wt%	65	66	82	63	66	65	69	64	66	64	66	67	70
MATERIAL RECOVERY wt%	99	101	104	99	99	99	99	96	98	96	97	97	97
RAW SHALE PROPERTIES:													
MOISTURE wt%									1.00 *				
FISCHER ASSAY gal/ton	26.0	24.7	25.4	25.5	25.4	24.9	25.7	25.4	26.8	25.0	26.4	25.9	26.2
FISCHER ASSAY OIL wt%	9.90	9.40	9.70	9.70	9.70	9.50	9.80	9.70	10.20	9.50	10.10	9.90	10.00
FISCHER ASSAY WATER wt%	1.34	1.35	1.60	1.30	1.30	1.30	1.30	1.50	1.30	1.40	1.40	1.40	1.50
FISCHER ASSAY GAS&LOSS wt%	2.24	2.20	2.30	3.90	3.90	2.70	5.40	3.80	2.50	3.20	2.00	2.40	2.40
MINERAL CO_2 wt%	17.71	18.18	18.08	17.69	17.69	16.95	16.98	17.08	17.83	17.91	17.57	17.68	17.68
IGNITION LOSS wt%	31.17	31.30	28.83	32.02	32.02	32.02	32.54	33.04	33.55	32.87	32.16	32.25	32.47
CARBON wt%									17.09 *				
HYDROGEN wt%									1.85 *				
NITROGEN wt%									0.51 *				
NOMINAL PART. SIZE in.	3/8X2	3/8X2	3/8X2	3/8X2	3/8X2	3/8X2	3/8X2	2X3/8	1.75X3/8	1.75X3/8	1.75X3/8	1.75X3/8	1.75X3/8
COLLECTED OIL PROPERTIES:													
GRAVITY DEGREE API	21.4	22.1	22.1	19.6	19.4	19.4	21.6	21.4	22.3	21.5	21.1	20.9	21.6
VISCOSITY SUS@ 130°F	80.2	73.0	69.4	144.6	144.2	148.2	85.8	94.1	73.8	94.0	99.4	107.5	83.8
VISCOSITY SUS@ 210°F	40.1	39.2	40.0	52.9	52.9	50.6	42.6	42.8	39.8	43.0	43.3	44.9	43.8
RAMSBOTTOM CARBON wt%	1.15	1.01	0.72	N/A	2.25	2.10	1.56	1.72	1.11	1.33	1.16	1.67	1.43
WATER CONTENT vol%	4.72	0.30	3.40	2.9	2.90	2.90	2.90	2.90	0.10	0	0.40	0.40	0.30
SOLIDS BOTTOM SED. wt%	0.11	0	0	Trace	Trace	Trace	0.09	Trace	Trace	Trace	0.30	0.40	Trace
CARBON wt%									84.65 *				
HYDROGEN wt%									11.49 *				
NITROGEN wt%									2.02 *				
PRODUCT GAS PROPERTIES:													
MOISTURE vol%									20 *				
ANALYSIS (DRY BASIS)													
H_2 vol%							3.17 *						
N_2 vol%							62.57 *						
O_2 vol%							0.05 *						
CO vol%							2.80 *						
CH_4 vol%							1.31 *						
CO_2 vol%							28.56 *						
C_2H_4 vol%							0.45 *						
C_2H_6 vol%							0.29 *						
C_3's vol%							0.27 *						
C_4's vol%							0.07 *						
C_5+'s vol%							0.43 *						
GROSS HEAT. VALUE BTU/SCF							83 *						
SPECIFIC GRAVITY							1.117 *						
RETORTED SHALE PROPERTIES:													
FISCHER ASSAY gal/ton	0.12	N/A	N/A	1.20	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FISCHER ASSAY OIL wt%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FISCHER ASSAY WATER wt%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FISCHER ASSAY GAS&LOSS wt%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
MINERAL CO_2 wt%	15.23	15.28	14.97	7.02	6.48	8.50	16.16	15.56	12.91	12.33	14.13	14.14	14.92
ORGANIC CARBON wt%	2.09	2.07	2.16	4.33	4.47	3.92	1.83	2.00	2.72	2.88	2.39	3.50	2.17
IGNITION LOSS wt%	17.00	12.17	15.90	7.58	8.46	11.01	19.90	19.18	15.62	15.04	16.33	16.99	17.52
CARBON wt%									6.24 *				
HYDROGEN wt%									0.16 *				
NITROGEN wt%									0.20 *				
MISCELLANEOUS:													
RETORT DROP in.H_2O/ft	0.79	0.94	1.06	0.16	0.12	0.33	0.51	0.61	1.42	1.42	1.63	1.81	1.05
CARBONATE DECOMP wt%	28	30	29	71	73	61	19	25	42	45	34	34	30
BED HEIGHT ft	24.54	24.54	24.54	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5

* DESIGNATED VALUES SEE TABLE D-1

TEST DATA FROM PILOT PLANT — DIRECT HEATED

TABLE D-2 (CONT.)

GENERAL: RUN NUMBER / TEST NUMBER	PP-6 G-2	PP-9 Step 7	PP-9 A-2	PP-9 B	PP-9 A	PP-10 B	PP-10 C
DATE	8/17/74	11/21/74	11/23/74	11/23/74	11/25/74	12/10/74	12/10/74
START TIME	1600	2200	1900	2300	0000	0000	0900
LENGTH OF TEST hrs	4	8	4	10	7	8	9
RATES AND QUANTITIES:							
TOP DISTRIBUTOR GAS SCF/T	1008	1416	1162	1232	1210	1184	1219
MID DISTRIBUTOR GAS SCF/T	1838	1469	1369	1425	1291	1387	1436
BTM DISTRIBUTOR GAS SCF/T	13814	14318	12033	12593	11177	12139	12457
TOTAL GAS SCF/T	16660	17203	14564	15250	13678	14710	15112
TOP DISTRIBUTOR AIR SCF/T	3439	3042	3154	3119	2865	3064	3120
MID DISTRIBUTOR AIR SCF/T	1660	1469	1494	1463	1372	1434	1478
BTM DISTRIBUTOR AIR SCF/T	0	0	0	0	0	0	0
TOTAL AIR SCF/T	5099	4511	4648	4582	4237	4498	4598
SHALE THROUGHPUT $lb/hr/ft^2$	411	465	587	633	604	613	640
TEMPERATURES:							
PRODUCT OIL °F	134	120	128	134	124	131	133
RETORTED SHALE OUT °F	345	311	370	421	428	383	438
RAW SHALE IN °F	92	60	34	50	51	23	32
RECYCLE GAS IN °F	249	238	237	246	245	246	245
OFF-GAS °F	162	132	143	162	135	141	144
AIR IN °F	253	196	188	192	188	180	180
YIELDS:							
OIL COLLECTED wt%F.A.	84.2	92.7	85.2	92.2	84.1	99.7	94.6
PRODUCT GAS (WET) SCF/T	6107	5769	5104	5353	4681	5452	5211
RETORTED SHALE wt%R.S.	83	81	83	83	81	83	85
LIQUID WATER lb/ton	13.11	5.83	1.04	0.21	0.34	0.28	0.27
ASH BALANCE wt%	101	100	100	100	100	100	101
ATM. N_2 BALANCE wt%	76	88	72	76	70	80	75
WATER BALANCE wt%	53	51	37	42	29	33	28
KEROGEN BALANCE wt%	103	87	92	98	88	111	130
ORG. CARBON BALANCE wt%	87	86	81	86	79	89	86
TOT. H_2 BALANCE wt%	91	94	86	91	83	95	93
ORG. N_2 BALANCE wt%	66	67	66	69	65	70	70
MATERIAL RECOVERY wt%	96	95	94	95	92	95	96
RAW SHALE PROPERTIES:							
MOISTURE wt%				1.00 *			
FISCHER ASSAY gal/ton	26.70	25.80	25.90	25.90	26.10	25.10	25.60
FISCHER ASSAY OIL wt%	10.20	9.85	9.88	9.88	9.97	9.60	9.76
FISCHER ASSAY WATER wt%	1.40	1.82	1.45	1.45	2.02	1.91	1.92
FISCHER ASSAY GAS&LOSS wt%	2.00	2.14	2.35	2.35	2.74	1.37	2.55
MINERAL CO_2 wt%	17.11	17.63	17.27	17.27	17.65	17.78	20.23
IGNITION LOSS wt%	32.61	31.78	31.54	31.54	32.98	31.40	31.99
CARBON wt%				17.09 *			
HYDROGEN wt%				1.85 *			
NITROGEN wt%				0.51 *			
NOMINAL PART. SIZE in.	1.75X3/8	½X2	½X2	½X2	½X2	½X2	½X2
COLLECTED OIL PROPERTIES:							
GRAVITY DEGREE API	19.9	20.9	21.2	21.1	21.8	21.2	21.2
VISCOSITY SUS @ 130°F	87.2	93.8	91.1	92.6	91.4	99.0	99.0
VISCOSITY SUS @ 210°F	43.1	41.9	41.5	42.2	41.0	42.3	42.3
RAMSBOTTOM CARBON wt%	1.46	1.42	1.62	1.34	1.79	1.48	1.48
WATER CONTENT vol%	6.60	3.07	0.56	0.11	0.17	0.14	0.14
SOLIDS BOTTOM SED. wt%	0.20	0.38	Trace	Trace	Trace	0	0
CARBON wt%				84.65 *			
HYDROGEN wt%				11.49 *			
NITROGEN wt%				2.02 *			
PRODUCT GAS PROPERTIES:							
MOISTURE vol%				20 *			
ANALYSIS (DRY BASIS)							
H_2 vol%	3.17 *	4.00	4.44	4.47	3.96	4.60	5.17
N_2 vol%	62.57 *	65.18	64.99	65.12	62.85	65.11	65.54
O_2 vol%	0.05 *	0	0	0	0	0	0
CO vol%	2.80 *	2.16	2.20	2.18	2.19	2.12	2.31
CH_4 vol%	1.31 *	2.20	2.18	2.19	2.10	2.26	2.56
CO_2 vol%	28.56 *	24.11	23.72	23.52	26.58	23.57	21.68
C_2H_4 vol%	0.45 *	0.56	0.58	0.58	0.61	0.56	0.59
C_2H_6 vol%	0.29 *	0.56	0.59	0.58	0.51	0.57	0.69
C_3's vol%	0.27 *	0.66	0.73	0.72	0.65	0.63	0.75
C_4's vol%	0.07 *	0.14	0.14	0.21	0.13	0.14	0.30
C_5+'s vol%				0.43 *			
GROSS HEAT. VALUE BTU/SCF	83 *	110	114	116	108	112	128
SPECIFIC GRAVITY	1.117 *	1.084	1.078	1.077	1.098	1.075	0.060
RETORTED SHALE PROPERTIES:							
FISCHER ASSAY gal/ton	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FISCHER ASSAY OIL wt%	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FISCHER ASSAY WATER wt%	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FISCHER ASSAY GAS&LOSS wt%	N/A	N/A	N/A	N/A	N/A	N/A	N/A
MINERAL CO_2 wt%	12.73	15.66	15.42	15.84	14.60	14.30	16.30
ORGANIC CARBON wt%	2.77	1.97	2.04	1.92	2.26	2.34	1.80
IGNITION LOSS wt%	17.73	15.18	17.25	17.62	16.90	16.52	18.72
CARBON wt%	*			6.24 *			
HYDROGEN wt%	*			0.16 *			
NITROGEN wt%	*			0.20 *			
MISCELLANEOUS:							
RETORT DROP in.H_2O/ft	0.87	0.73	1.35	1.58	1.06	1.26	1.45
CARBONATE DECOMP. wt%	38	29	26	23	33	34	32
BED HEIGHT ft	23.5	23.5	23.5	23.5	23.5	23.5	23.5

* DESIGNATED VALUES SEE TABLE D-1

TEST DATA FROM PILOT PLANT — DIRECT HEATED

TABLE D-2 (CONT.)

GENERAL: RUN NUMBER / TEST NUMBER	PP-10 D	PP-10 D-2	PP-16 A-1	PP-16 A-2	PP-16 A-3	PP-16 A-4	PP-16 A-5	PP-16 A-6	PP-16 A-7	PP-16 B-1	PP-16 B-2	PP-16 B-3	PP-16 C-1		
DATE	12/10/74	12/11/74	12/23/75	12/24/75	12/25/75	12/26/75	12/27/75	12/28/75	12/29/75	1/02/76	1/03/76	1/04/76	1/05/76		
START TIME	1900	1000	0800	0800	0800	0800	0800	0800	0800	0800	0800	0800	0800		
LENGTH OF TEST hrs	15	23	24	24	24	24	24	24	24	24	24	24	24		
RATES AND QUANTITIES:															
TOP DISTRIBUTOR GAS SCF/T	991	1022	1596	1537	1537	1537	1521	1526	1515	1468	1437	1402	1738		
MID DISTRIBUTOR GAS SCF/T	1445	1521	1513	1506	1519	1518	1509	1532	1479	1957	1940	1915	1645		
BTM DISTRIBUTOR GAS SCF/T	12668	13191	14327	14170	13988	13949	13859	13812	13959	14257	13713	13527	14740		
TOTAL GAS SCF/T	15104	15734	17436	17213	17044	17004	16889	16870	16953	17682	17090	16844	18123		
TOP DISTRIBUTOR AIR SCF/T	3239	3332	4673	4512	4345	4334	4286	4395	4430	4165	4024	4002	4880		
MID DISTRIBUTOR AIR SCF/T	2706	1573	1115	971	1031	1051	1014	1021	1022	1884	1838	1843	680		
BTM DISTRIBUTOR AIR SCF/T	0	0	0	0	0	0	0	0	0	0	0	0	0		
TOTAL AIR SCF/T	5945	4905	5788	5483	5376	5385	5300	5416	5452	6049	5862	5845	5560		
SHALE THROUGHPUT lb/hr/ft^2	622	605	380	396	395	396	404	401	400	398	407	409	394		
TEMPERATURES:															
PRODUCT OIL °F	144	129	154	164	160	159	141	149	147	141	145	151	167		
RETORTED SHALE OUT °F	412	425	367	376	394	390	397	402	393	408	425	433	393		
RAW SHALE IN °F	25	49	83	81	76	81	81	75	78	43	66	66	57		
RECYCLE GAS IN °F	160	242	319	321	320	320	313	318	317	291	295	294	294		
OFF-GAS °F	161	140	154	160	147	152	144	148	146	145	157	156	154		
AIR IN °F	180	179	191	195	199	194	189	187	188	173	181	182	185		
YIELDS:															
OIL COLLECTED wt%F.A.	78.7	85.8	85.6	82.5	86.3	90.6	95.4	95.5	90.8	103.3	83.7	88.9	81.7		
PRODUCT GAS (WET) SCF/T	5620	5191	8654	8238	8086	8053	7968	8146	8154	9052	8802	8767	8351		
RETORTED SHALE wt%R.S.	84	84	80	76	77	78	78	79	78	78	79	78	77		
LIQUID WATER lb/ton	15.74	5.65	0.62	0.94	0.69	0.86	1.09	1.01	0.93	1.87	2.58	2.99	20.29		
ASH BALANCE wt%	100	101	100	100	100	100	100	101	100	100	100	100	100		
ATM. N_2 BALANCE wt%	76	70	96	94	94	95	96	94	96	97	96	96	95		
WATER BALANCE wt%	56	36	90	69	75	71	69	79	76	78	81	70	71		
KEROGEN BALANCE wt%	96	102	91	81	88	93	90	92	90	101	85	94	86		
ORG. CARBON BALANCE wt%	82	86	92	81	90	93	90	100	98	106	89	95	88		
TOT. H_2 BALANCE wt%	93	93	99	94	102	103	100	110	110	118	103	108	116		
ORG. N_2 BALANCE wt%	66	69	57	55	58	60	62	59	59	89	65	60	57		
MATERIAL RECOVERY wt%	96	94	99	97	98	98	98	99	98	100	98	98	97		
RAW SHALE PROPERTIES:															
MOISTURE wt%	1.00 * →	→	0.55	0.99	0.95	0.91	0.91	1.01	1.11	1.16	1.10	1.19	1.31		
FISCHER ASSAY gal/ton	27.70	28.10	29.60	28.80	29.10	28.0	27.0	27.7	27.4	28.0	26.0	28.1	27.70		
FISCHER ASSAY OIL wt%	10.58	10.72	11.31	11.00	11.11	10.71	10.30	10.56	10.47	10.68	9.91	10.72	10.58		
FISCHER ASSAY WATER wt%	1.54	1.96	1.63	1.60	1.42	1.44	1.49	1.51	1.48	1.15	1.54	1.70	2.01		
FISCHER ASSAY GAS&LOSS wt%	2.36	2.89	2.07	1.95	2.79	2.32	1.80	2.18	1.98	2.04	2.26	1.88	1.96		
MINERAL CO_2 wt%	17.34	17.47	17.61	17.42	17.58	17.90	17.85	17.42	17.59	17.80	17.56	17.66	17.53		
IGNITION LOSS wt%	32.12	32.23	33.77	34.25	33.54	33.54	33.88	33.29	33.08	33.10	33.03	33.72	33.56		
CARBON wt%	17.09 * →	→	17.44	18.00	17.30	17.43	17.61	16.90	16.36	16.79	16.63	17.08	17.06		
HYDROGEN wt%	1.85 * →	→	1.82	1.89	1.80	1.83	1.85	1.75	1.67	1.79	1.73	1.80	1.72		
NITROGEN wt%	0.51 * →	→	0.54	0.54	0.54	0.54	0.53	0.54	0.53	0.51	0.53	0.54	0.52		
NOMINAL PART. SIZE in.	½X2	½X2	½X2	½X2	½X2	½X2	½X2	½X2	½X2	½X2	½X2	½X2	½X2		
COLLECTED OIL PROPERTIES:															
GRAVITY DEGREE API	20.7	21.2	20.4	20.2	20.2	20.3	20.5	20.5	20.3	20.4	20.9	20.9	20.9		
VISCOSITY SUS @ 130°F	111.5	97.5	113.6	119.4	115.9	110.1	104.2	108.3	102.4	104.5	99.7	99.7	103.3		
VISCOSITY SUS @ 210°F	44.7	43.1	50.9	51.7	51.5	50.7	49.8	53.7	50.9	50.8	50.6	50.6	50.6		
RAMSBOTTOM CARBON wt%	1.83	1.81	1.88	1.72	1.79	1.67	1.55	1.50	1.72	1.91	1.76	1.74	1.99		
WATER CONTENT vol%	7.77	2.63	0.32	0.46	0.32	0.42	0.51	0.44	0.46	0.78	1.49	1.40	9.78		
SOLIDS BOTTOM SED. wt%	1.98	0.66	0.32	0.10	0.10	0.10	0.10	0.10	Trace	Trace	0.14	0.14	0.28		
CARBON wt%	←						84.65 *	→							
HYDROGEN wt%	←						11.49 *	→							
NITROGEN wt%	←						2.02 *	→							
PRODUCT GAS PROPERTIES:															
MOISTURE vol%	←								20 *	→					
ANALYSIS (DRY BASIS)															
H_2 vol%	5.01	4.70	0	2.95	2.99	2.76	2.76	2.99	1.85	2.61	3.10	3.14	3.53		
N_2 vol%	63.94	65.29	63.32	62.02	61.60	63.02	63.02	6 .20	63.54	63 97	63.36	63.00	62.66		
O_2 vol%	0	0	0	0	0	0	0	0	0	0.31	0	0	0		
CO vol%	2.30	2.49	3.24	2.72	2.72	2.37	2.36	2.76	3.02	2.44	2.33	2.46	2.92		
CH_4 vol%	2.25	2.41	1.05	1.06	1.04	1.13	1.12	1.18	1.26	1.35	1.46	1.59	1.37		
CO_2 vol%	24.16	22.47	31.21	29.97	30.34	29.32	29.33	29.37	28.77	27.68	28.14	28.01	27.94		
C_2H_4 vol%	0.61	0.68	0.32	0.36	0.36	0.37	0.37	0.40	0.43	0.48	0.53	0.56	0.49		
C_2H_6 vol%	0.54	0.65	0.23	0.24	0.24	0.26	0.26	0.27	0.30	0.30	0.30	0.38	0.28		
C_3's vol%	0.62	0.73	0.20	0.21	0.20	0.25	0.24	0.24	0.29	0.29	0.28	0.30	0.28		
C_4's vol%	0.15	0.15	0	0.05	0.09	0.07	0.07	0.09	0.11	0.13	0.08	0.12	0.11		
C_5+'s vol%	←								0.43 *	→					
GROSS HEAT. VALUE BTU/SCF	114	121	62	73	74	76	76	78	79	82	83	90	86		
SPECIFIC GRAVITY	1.074	1.068	1.159	1.126	1.129	1.125	1.125	1.123	1.130	1.117	1.114	1.113	1.110		
RETORTED SHALE PROPERTIES:															
FISCHER ASSAY gal/ton	N/A	N/A	0.30	0.20	0.30	0.30	0.30	0.30	0.30	0.20	0.20	0.30	0.50		
FISCHER ASSAY OIL wt%	N/A	N/A	0.10	0.08	0.10	0.10	0.10	0.11	0.10	0.08	0.09	0.11	0.20		
FISCHER ASSAY WATER wt%	N/A	N/A	0.16	0.17	0.13	0.21	0.03	0.04	0.10	0	0	0.04	0.32		
FISCHER ASSAY GAS&LOSS wt%	N/A	N/A	0.03	0.11	0.07	0.10	0.09	0.03	0.08	0.12	0.12	0.15	0		
MINERAL CO_2 wt%	15.57	15.63	12.41	12.20	12.64	13.03	13.03	13.22	13.46	12.65	13.21	12.78	12.20		
ORGANIC CARBON wt%	1.99	1.98	1.52	1.43	1.58	2.10	1.80	1.90	1.50	1.42	1.46	1.76	2.12		
IGNITION LOSS wt%	18.34	18.00	13.40	13.19	13.54	14.44	14.13	13.81	14.02	13.22	13.97	14.14	13.42		
CARBON wt%	6.24 * →	→	4.91	4.76	5.03	5.65	5.35	5.50	5.17	4.87	5.06	5.23	5.45		
HYDROGEN wt%	0.16 * →	→	0.09	0.09	0.12	0.14	0.10	0.11	0.11	0.11	0.11	0.12	0.12		
NITROGEN wt%	0.20 * →	→	0.15	0.15	0.16	0.17	0.17	0.15	0.16	0.30	0.23	0.17	0.16		
MISCELLANEOUS:															
RETORT DROP in.H_2O/ft	1.29	1.33	N/A	0.68	1.06	N/A	N/A	N/A	0.62	0.65	0.67	0.68	0.65		
CARBONATE DECOMP. wt%	25	25	46	47	44	43	44	40	40	45	41	44	46		
BED HEIGHT ft	23.5	23.5	24.08	24.08	24.08	24.08	24.08	24.08	24.08	24.08	24.08	24.08	24.08		

* DESIGNATED VALUES SEE TABLE D-1

TEST DATA FROM PILOT PLANT — DIRECT HEATED
TABLE D-2 (CONT.)

GENERAL: RUN NUMBER / TEST NUMBER	PP-16 C-3	PP-16 C-4	PP-16 D-1	PP-16 A-8	PP-16 A-9	PP-19 D	PP-19 K	PP-19 J
DATE	1/7/76	1/8/76	1/11/76	1/27/76	1/30/76	4/9/76	4/10/76	4/11/76
START TIME	0800	0800	2400	0800	0800	2000	1800	1000
LENGTH OF TEST hrs	24	24	28	48	72	14	14	24
RATES AND QUANTITIES:								
TOP DISTRIBUTOR GAS SCF/T	1827	1757	1515	1653	1412	1415	757	641
MID DISTRIBUTOR GAS SCF/T	1682	1616	1480	1575	1354	1616	1386	1484
BTM DISTRIBUTOR GAS SCF/T	15016	14590	13497	14677	12770	14994	14555	13599
TOTAL GAS SCF/T	18528	17963	16492	17905	15536	18025	16698	15724
TOP DISTRIBUTOR AIR SCF/T	5216	5014	4190	4281	3812	4843	3360	2871
MID DISTRIBUTOR AIR SCF/T	601	576	1323	1006	876	849	2494	2299
BTM DISTRIBUTOR AIR SCF/T	0	0	0	0	0	0	272	0
TOTAL AIR SCF/T	5817	5590	5513	5287	4688	5694	6126	5170
SHALE THROUGHPUT $lb/hr/ft^2$	385	398	420	407	459	387	402	425
TEMPERATURES:								
PRODUCT OIL °F	77	171	175	170	160	105	140	140
RETORTED SHALE OUT °F	401	379	443	365	440	369	454	435
RAW SHALE IN °F	33	71	76	60	60	70	70	70
RECYCLE GAS IN °F	295	296	296	272	270	256	260	260
OFF-GAS °F	153	158	145	155	130	169	156	143
AIR IN °F	182	185	191	190	193	206	210	220
YIELDS:								
OIL COLLECTED wt%F.A.	87.7	87.1	90.5	98.2	80.6	86.1	86.8	90.2
PRODUCT GAS (WET) SCF/T	8725	8388	8298	7904	7009	8553	9203	7736
RETORTED SHALE wt%R.S.	75	77	77	82	81	74	76	74
LIQUID WATER lb/ton	22.50	15.49	2.34	15.40	16.90	11.28	8.16	0.40
ASH BALANCE wt%	100	100	100	101	100	100	101	100
ATM N_2 BALANCE wt%	95	94	98	89	94	93	94	90
WATER BALANCE wt%	70	74	54	108	84	68	77	41
KEROGEN BALANCE wt%	81	87	95	101	85	87	91	88
ORG. CARBON BALANCE wt%	84	89	95	101	84	83	88	80
TOT. H_2 BALANCE wt%	113	107	108	118	101	103	109	105
ORG. N_2 BALANCE wt%	51	52	59	68	65	59	71	62
MATERIAL RECOVERY wt%	96	97	97	101	98	97	99	94
RAW SHALE PROPERTIES:								
MOISTURE wt%	0.96	1.30	1.51	1.06	0.88	1.04	0.80	1.29
FISCHER ASSAY gal/ton	26.40	26.8	26.7	27.3	28.3	31.65	31.8	31.6
FISCHER ASSAY OIL wt%	10.06	10.24	10.20	10.41	10.82	12.09	12.15	12.05
FISCHER ASSAY WATER wt%	1.52	1.29	1.54	1.98	1.56	1.41	1.43	1.40
FISCHER ASSAY GAS&LOSS wt%	2.03	1.76	1.76	1.95	2.02	1.97	1.60	2.22
MINERAL CO_2 wt%	17.92	17.54	17.50	17.70	17.10	17.64	17.25	17.90
IGNITION LOSS wt%	33.34	32.25	32.29	33.27	33.59	34.52	34.12	34.79
CARBON wt%	16.60	16.36	16.06	17.06	17.57	18.72	18.32	18.99
HYDROGEN wt%	1.71	1.72	1.68	1.79	1.88	1.98	1.93	2.01
NITROGEN wt%	0.51	0.53	0.50	0.55	0.53	0.51	0.51	0.52
NOMINAL PART. SIZE in.	¼X2	¼X2	¼X2	¼X2	¼X2	¼X2	¼X2	¼X2
COLLECTED OIL PROPERTIES:								
GRAVITY DEGREE API	19.8	19.8	20.0	19.7	20.5	19.9	19.7	20.2
VISCOSITY SUS @ 130°F	123.1	122.2	116.3	112.1	98.9	125.9	128.8	112.2
VISCOSITY SUS @ 210°F	53.5	52.7	51.5	53.6	50.3	52.1	49.7	51.8
RAMSBOTTOM CARBON wt%	20.50	1.94	2.01	2.01	1.92	2.33	2.29	2.24
WATER CONTENT vol%	10.60	7.49	1.16	6.50	8.20	4.80	3.47	0.17
SOLIDS BOTTOM SED. wt%	0.16	0.16	0.15	0.15	0.22	0.23	0.24	0
CARBON wt%			84.65 *			83.63	83.93	83.93
HYDROGEN wt%			11.49 *			11.60	11.59	11.59
NITROGEN wt%			2.02 *			2.27	2.28	2.28
PRODUCT GAS PROPERTIES:								
MOISTURE vol%				20 *				
ANALYSIS (DRY BASIS)								
H_2 vol%	3.39	2.98	2.80	7.85	4.77	4.28	4.24	6.57
N_2 vol%	62.70	62.11	64.10	58.61	62.03	60.80	61.72	59.34
O_2 vol%	0.10	0.07	0	0.12	0.39	0	0	0.50
CO vol%	3.28	3.18	2.11	3.28	2.98	4.08	3.49	3.88
CH_4 vol%	1.22	0.99	1.22	1.09	2.68	1.00	1.25	2.49
CO_2 vol%	27.73	29.43	28.43	27.85	24.57	28.68	28.06	24.99
C_2H_4 vol%	0.50	0.32	0.42	0.32	0.79	0.30	0.39	0.62
C_2H_6 vol%	0.28	0.23	0.27	0.24	0.66	0.23	0.26	0.59
C_3's vol%	0.28	0.21	0.23	0.21	0.58	0.21	0.12	0.48
C_4's vol%	0.10	0.05	0	0	0.12	0	0.06	0.13
C_5+'s vol%				0.43 *				
GROSS HEAT. VALUE BTU/SCF	85	74	73	90	123	79	81	124
SPECIFIC GRAVITY	1.111	1.124	1.118	1.070	1.077	1.107	1.103	1.063
RETORTED SHALE PROPERTIES:								
FISCHER ASSAY gal/ton	0.20	0.20	0.20	0.20	0.30	0.24	0.20	0.21
FISCHER ASSAY OIL wt%	0.06	0.05	0.07	0.09	0.10	0.09	0.08	0.08
FISCHER ASSAY WATER wt%	0.14	0.25	0.17	0.19	0.23	0.16	0.11	0.13
FISCHER ASSAY GAS&LOSS wt%	0.02	0.10	0.09	0.09	0.02	0.17	0.16	0.06
MINERAL CO_2 wt%	10.43	10.94	10.73	15.80	15.08	10.89	10.80	10.38
ORGANIC CARBON wt%	1.11	1.34	1.81	1.61	1.67	1.49	1.48	1.44
IGNITION LOSS wt%	10.53	11.53	12.26	16.68	16.70	11.84	11.92	11.23
CARBON wt%	3.95	4.32	4.74	5.92	5.78	4.46	4.42	4.27
HYDROGEN wt%	0.09	0.09	0.10	0.18	0.15	0.11	0.12	0.10
NITROGEN wt%	0.11	0.13	0.14	0.21	0.21	0.09	0.16	0.10
MISCELLANEOUS:								
RETORT DROP $in.H_2O/ft$	0.65	0.57	0.55	0.67	0.60	0.59	0.66	N/A
CARBONATE DECOMP wt%	56	52	52	27	29	54	52	57
BED HEIGHT ft	24.08	24.08	24.08	24.08	24.08	24.08	24.08	24.08

* DESIGNATED VALUES. SEE TABLE D-1

TEST DATA FROM SEMI-WORKS — DIRECT HEATED

TABLE D-3

GENERAL: RUN NUMBER / TEST NUMBER	SW-5 A-1	SW-5 A-2	SW-5 A-3	SW-5 A-4	SW-7 A	SW-7 B	SW-7 D	SW-7 E	SW-7 B-1	SW-7 J	SW-7 K	SW-7 K-1	SW-7 K-2
DATE	12/24/74	12/26/74	12/28/74	12/29/74	1/20/75	1/22/75	1/23/75	1/24/75	1/28/75	1/29/75	1/30/75	2/7/75	2/8/75
START TIME	1600	2400	0800	0800	1600	1600	2400	2400	0800	1600	2400	2400	0800
LENGTH OF TEST HRS.	24	32	8	8	40	16	8	8	24	24	32	8	24
RATES AND QUANTITIES:													
TOP DISTRIBUTOR GAS SCF/T	1458	1218	1276	1250	1818	1911	1583	1357	1844	1374	1181	1307	1283
MID DISTRIBUTOR GAS SCF/T	1646	1709	1806	1782	1938	1837	1561	1375	1742	1575	1491	1500	1498
BTM DISTRIBUTOR GAS SCF/T	13825	15141	15363	15132	13653	14537	13847	12480	13770	14003	14886	13322	13097
TOTAL GAS SCF/T	16929	18068	18445	18164	17409	18285	16991	15212	17356	16952	17558	16129	15878
TOP DISTRIBUTOR AIR SCF/T	2883	3492	3690	3605	5555	5781	4789	3792	5474	4852	4280	4735	4577
MID DISTRIBUTOR AIR SCF/T	1538	1686	1751	1740	0	0	330	373	0	329	408	546	450
BTM DISTRIBUTOR AIR SCF/T	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL AIR SCF/T	4421	5178	5441	5345	5555	5781	5119	4165	5474	5181	4688	5281	5027
SHALE THROUGHPUT lb/hr/ft^2	451	422	401	408	343	362	435	549	383	436	502	455	465
TEMPERATURES:													
PRODUCT OIL °F	155	156	155	156	155	155	155	160	185	195	194	174	169
RETORTED SHALE OUT °F	373	349	336	324	325	328	337	376	277	328	302	369	377
RAW SHALE IN °F	30	30	30	30	33	30	30	35	38	37	40	47	42
RECYCLE GAS IN °F	176	176	187	170	281	282	250	267	267	268	271	265	263
OFF-GAS °F	177	184	196	176	174	175	187	174	177	174	193	155	157
AIR IN °F	150	150	150	150	235	231	230	231	223	231	231	231	240
YIELDS:													
OIL COLLECTED wt%F.A.	93.4	92.0	83.3	93.8	96.1	100.3	90.3	86.2	84.8	81.3	84.4	90.4	83.4
PRODUCT GAS (WET) SCF/T	7331	8001	8396	8191	9641	9375	7861	6054	8309	7627	6481	7467	5912
RETORTED SHALE wt%R.S.	84	81	82	81	78	79	82	85	78	82	82	80	82
LIQUID WATER lb/ton	0.32	0.51	0.30	0.32	0.39	0.50	4.73	4.45	10.30	2.52	0.99	0.21	0.66
ASH BALANCE wt%	100	99	100	100	100	100	100	100	99	100	100	100	100
ATM. N_2 BALANCE wt%	107	97	97	97	108	102	99	96	94	91	87	87	74
WATER BALANCE wt%	86	76	74	69	95	85	63	58	67	67	55	48	39
KEROGEN BALANCE wt%	110	102	102	107	106	109	110	104	99	103	95	109	99
ORG. CARBON BALANCE wt%	96	96	92	101	100	107	97	94	100	89	88	91	84
TOTAL H_2 BALANCE wt%	105	105	99	109	113	125	108	126	109	101	101	101	94
ORG. N_2 BALANCE wt%	69	67	64	69	60	69	74	73	68	59	65	69	65
MATERIAL RECOVERY wt%	103	100	100	100	103	102	100	99	98	99	97	97	94
RAW SHALE PROPERTIES:													
MOISTURE wt%	←						1.00 *						→
FISCHER ASSAY gal/ton	26.0	25.6	25.4	26.6	28.5	27.7	27.4	27.00	29.8	27.2	27.6	26.0	26.6
FISCHER ASSAY OIL wt%	9.9	9.8	9.7	10.2	10.9	10.56	10.46	10.30	11.36	10.41	10.51	9.94	10.17
FISCHER ASSAY WATER wt%	1.7	1.8	1.75	1.6	1.83	1.79	1.85	1.89	1.75	1.73	1.67	1.69	1.68
FISCHER ASSAY GAS&LOSS wt%	2.2	2.5	2.1	2.2	2.55	2.33	2.47	2.36	2.41	1.95	2.39	1.98	2.01
MINERAL CO_2 wt%	16.87	17.12	17.46	17.25	17.41	13.48	17.58	17.73	17.88	17.63	17.04	18.82	18.34
IGNITION LOSS wt%	31.50	32.48	31.63	31.94	33.44	33.29	32.36	32.76	33.19	31.76	32.74	32.24	32.37
CARBON wt%	←		17.09 *	→	17.91	16.97	17.09 *	17.03	17.09 *	16.81	16.51	16.69	16.26
HYDROGEN wt%	←		1.85 *	→	1.92	1.75	1.85 *	1.51	1.85 *	1.77	1.74	1.74	1.71
NITROGEN wt%	←		0.51 *	→	0.60	0.53	0.51 *	0.56	0.51 *	0.55	0.53	0.50	0.52
NOMINAL PART. SIZE in.	3/8X2	3/8X2	3/8X2	3/8X2	½X2½	½X2½	½X2½	½X2½	½X2½	½X2½	½X2½	½X2½	½X2½
COLLECTED OIL PROPERTIES:													
GRAVITY DEGREE API	20.6	20.4	19.7	19.9	19.6	19.7	19.6	20.0	19.4	19.9	19.3	19.9	20.1
VISCOSITY SUS @ 130°F	115.4	119.6	134.1	130.7	150.5	141.0	144.4	119.2	141.7	126.1	142.3	125.2	124.4
VISCOSITY SUS @ 210°F	44.8	45.4	46.7	46.7	48.5	47.3	47.6	44.8	47.8	45.9	47.6	46.0	43.7
RAMSBOTTOM CARBON wt%	1.78	1.73	1.65	1.97	2.24	N/A	2.30	1.98	2.19	1.83	2.18	1.86	1.75
WATER CONTENT vol%	0.15	0.27	0.18	0.16	0.17	0.21	0.04	0.08	0.29	0.21	0.24	0.12	0.35
SOLIDS BOTTOM SED. wt%	0.29	0.54	0.43	0.30	0.30	0.39	0.48	1.25	0.36	0.30	0.70	0.18	0.16
CARBON wt%	←			84.65 *	←	→	84.84	←	84.65 *	→	84.20	84.00	84.34
HYDROGEN wt%	←			11.49 *	←	→	11.36	←	11.49 *	→	11.19	11.11	11.19
NITROGEN wt%	←			2.02 *	←	→	2.27	←	2.02 *	→	2.21	2.15	2.26
PRODUCT GAS PROPERTIES:													
MOISTURE vol%	←						20 *						→
ANALYSIS (DRY BASIS)													
H_2 vol%	5.21	5.53	4.60	5.18	5.03	5.04	5.74	5.50	4.99	5.45	5.59	4.88	4.94
N_2 vol%	63.52	62.11	62.26	62.25	61.33	62.25	63.77	65.16	61.10	61.23	62.35	61.05	62.17
O_2 vol%	0	0	0	0	0.15	0.13	0.10	0.37	0.24	0.17	0.29	0.03	0.97
CO vol%	2.70	2.18	2.83	3.15	4.04	3.38	3.76	2.83	4.26	4.04	3.53	3.62	3.49
CH_4 vol%	2.55	2.18	2.07	2.29	1.59	1.64	2.19	2.60	1.53	1.75	2.26	1.56	1.69
CO_2 vol%	23.21	25.70	26.01	24.71	26.11	25.70	22.02	20.44	26.33	25.51	23.40	27.02	24.79
C_2H_4 vol%	0.77	0.72	0.78	0.76	0.55	0.52	0.73	0.89	0.45	0.55	0.80	0.46	0.52
C_2H_6 vol%	0.64	0.49	0.43	0.51	0.35	0.38	0.52	0.67	0.33	0.38	0.52	0.37	0.40
C_3's vol%	0.68	0.50	0.44	0.53	0.35	0.42	0.52	0.80	0.34	0.44	0.59	0.39	0.44
C_4's vol%	0.29	0.16	0.15	0.21	0.06	0.12	0.21	0.32	0	0.05	0.25	0.21	0.18
C_5+'s vol%	←						0.43 **						→
GROSS HEAT. VALUE BTU/SCF	129	113	109	119	100	101	122	138	95	105	126	102	104
SPECIFIC GRAVITY	1.068	1.078	1.088	1.076	1.085	1.084	1.056	1.051	1.086	1.078	1.066	1.093	1.081
RETORTED SHALE PROPERTIES:													
FISCHER ASSAY gal/ton	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FISCHER ASSAY OIL wt%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FISCHER ASSAY WATER wt%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FISCHER ASSAY GAS&LOSS wt%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
MINERAL CO_2 wt%	15.64	14.52	13.59	13.56	12.89	13.48	14.42	17.14	12.59	14.16	15.12	13.00	14.81
ORGANIC CARBON wt%	1.98	2.28	2.53	2.54	1.96	1.79	2.31	2.42	2.81	1.73	1.40	1.89	1.49
IGNITION LOSS wt%	17.98	16.82	15.60	15.42	14.51	15.15	16.84	19.90	14.26	16.11	17.56	14.94	17.07
CARBON wt%	←		6.24 *	→	5.47	5.47	6.24 *	7.09	6.24 *	5.59	5.52	5.43	5.53
HYDROGEN wt%	←		0.16 *	→	0.15	0.15	0.16 *	0.27	0.16 *	0.14	0.14	0.12	0.14
NITROGEN wt%	←		0.20 *	→	0.19	0.19	0.20 *	0.27	0.20 *	0.19	0.18	0.19	0.18
MISCELLANEOUS:													
RETORT DROP in. H_2O/ft	1.76	1.67	1.46	1.61	0.92	1.02	1.27	1.40	0.65	1.27	1.89	1.34	1.51
CARBONATE DECOMP. wt%	22	31	37	36	42	39	33	18	45	34	27	45	34
BED HEIGHT ft	25.58	25.58	25.58	25.58	25.58	25.58	25.58	25.58	25.58	25.58	25.58	25.58	25.58

* DESIGNATED VALUES SEE TABLE D-1

TEST DATA FROM SEMI-WORKS — DIRECT HEATED

TABLE D-3(CONT.)

GENERAL: RUN NUMBER / TEST NUMBER	SW-7 K-3	SW-7 K-4	SW-7 K-5	SW-7 K-6	SW-7 E-1	SW-7 F	SW-7 PC-1
DATE	2/9/75	2/10/75	2/12/75	2/13/75	2/18/75	2/19/75	2/21/75
START TIME	0800	0800	2400	0800	2400	1200	1600
LENGTH OF TEST HRS	24	22	8	16	8	6	16
RATES AND QUANTITIES:							
TOP DISTRIBUTOR GAS SCF/T	1274	1321	1339	1356	1497	1329	1382
MID DISTRIBUTOR GAS SCF/T	1492	1531	1552	1553	1604	1527	1606
BTM DISTRIBUTOR GAS SCF/T	12955	13443	13585	13883	14600	14135	14994
TOTAL GAS SCF/T	15721	16295	16476	16792	17701	16991	17982
TOP DISTRIBUTOR AIR SCF/T	4465	4646	4863	4869	4440	3924	3237
MID DISTRIBUTOR AIR SCF/T	326	499	465	469	518	656	1575
BTM DISTRIBUTOR AIR SCF/T	0	0	0	0	0	0	0
TOTAL AIR SCF/T	4791	5145	5328	5338	4958	4580	4812
SHALE THROUGHPUT $lb/hr/ft^2$	470	454	435	431	480	543	391
TEMPERATURES:							
PRODUCT OIL °F	176	183	151	158	143	148	180
RETORTED SHALE OUT °F	371	364	381	372	360	374	345
RAW SHALE IN °F	40	40	40	50	40	45	30
RECYCLE GAS IN °F	258	259	282	282	243	243	242
OFF-GAS °F	160	161	177	186	152	157	144
AIR IN °F	240	234	235	243	229	235	243
YIELDS:							
OIL COLLECTED wt% F.A.	83.0	90.8	75.8	81.7	98.5	96.7	93.9
PRODUCT GAS (WET) wt% R.S.	6351	6799	7109	7077	5907	5361	5272
RETORTED SHALE wt% R.S.	82	82	80	81	82	83	83
LIQUID WATER lb/ton	0.40	1.25	1.24	1.14	2.56	1.68	9.21
ASH BALANCE wt%	100	100	100	100	100	100	100
ATM. N_2 BALANCE wt%	84	83	83	82	77	73	72
WATER BALANCE wt%	47	57	56	52	38	50	42
KEROGEN BALANCE wt%	96	99	87	93	107	97	104
ORG. CARBON BALANCE wt%	88	92	79	89	94	88	95
TOT. H_2 BALANCE wt%	98	101	90	100	105	94	104
ORG. N_2 BALANCE wt%	68	70	58	64	72	74	73
MATERIAL RECOVERY wt%	96	97	95	95	95	95	95
RAW SHALE PROPERTIES:							
MOISTURE wt%	←	→	1.00 * ←			→	0.95
FISCHER ASSAY gal/ton	26.1	26.1	27.8	26.9	25.8	26.6	28.8
FISCHER ASSAY OIL wt%	9.96	9.98	10.63	10.28	9.88	10.14	10.97
FISCHER ASSAY WATER wt%	1.81	1.62	1.64	1.74	1.87	1.50	1.73
FISCHER ASSAY GAS&LOSS wt%	1.98	1.97	2.32	2.14	2.91	2.45	1.93
MINERAL CO_2	17.75	17.74	17.16	17.48	17.80	17.33	17.38
IGNITION LOSS wt%	32.25	32.30	32.86	32.64	31.47	32.11	32.89
CARBON wt%	16.18	16.66	17.28	16.35	16.61	17.90	17.17
HYDROGEN wt%	1.69	1.76	1.83	1.70	1.76	1.92	1.83
NITROGEN wt%	0.51	0.53	0.55	0.52	0.53	0.55	0.53
NOMINAL PART. SIZE in.	½X2½	½X2½	½X2½	½X2½	½X2½	½X2½	3/4X2-3/4
COLLECTED OIL PROPERTIES:							
GRAVITY DEGREE API	20.2	20.3	19.6	19.4	20.8	20.9	21.3
VISCOSITY SUS @ 130°F	123.7	117.9	148.5	148.7	101.8	99.5	97.2
VISCOSITY SUS @ 210°F	45.6	44.7	48.6	49.0	43.3	41.9	42.5
RAMSBOTTOM CARBON wt%	1.93	1.73	2.17	2.19	1.63	1.34	1.56
WATER CONTENT vol%	0.22	0.62	0.70	0.27	1.18	0.77	2.65
SOLIDS BOTTOM SED. wt%	0.19	0.29	0.70	0.60	1.62	1.42	2.02
CARBON wt%	84.25	84.03	84.41	84.67	84.65 *	84.14	84.65 *
HYDROGEN wt%	11.27	11.15	11.24	11.31	11.49 *	11.25	11.49 *
NITROGEN wt%	2.21	2.20	2.19	2.24	2.02 *	1.95	2.02 *
PRODUCT GAS PROPERTIES:							
MOISTURE vol%	←		→	20 * ←			→
ANALYSIS (DRY BASIS)							
H_2 vol%	5.18	5.03	4.72	5.16	5.33	5.61	5.09
N_2 vol%	62.61	62.23	61.54	61.30	64.16	61.12	64.57
O_2 vol%	0.06	0.18	0.28	0.18	0.26	0.03	0.18
CO vol%	3.58	3.56	3.59	4.02	3.19	3.10	2.36
CH_4 vol%	1.87	1.70	1.70	1.62	2.24	2.45	2.51
CO_2 vol%	24.44	25.23	26.32	25.92	22.25	25.01	22.58
C_2H_4 vol%	0.65	0.58	0.59	0.54	0.66	0.74	0.63
C_2H_6 vol%	0.45	0.40	0.37	0.38	0.56	0.60	0.64
C_3's vol%	0.49	0.45	0.40	0.39	0.66	0.65	0.73
C_4's vol%	0.25	0.21	0.08	0.08	0.26	0.27	0.29
C_5+'s vol%	←		→	0.43 * ←			→
GROSS HEAT. VALUE BTU/SCF	114	107	100	102	124	129	127
SPECIFIC GRAVITY	1.076	1.082	1.089	1.083	1.063	1.074	1.066
RETORTED SHALE PROPERTIES:							
FISCHER ASSAY gal/ton	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FISCHER ASSAY OIL wt%	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FISCHER ASSAY WATER wt%	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FISCHER ASSAY GAS&LOSS wt%	N/A	N/A	N/A	N/A	N/A	N/A	N/A
MINERAL CO_2 wt%	14.91	15.28	13.67	13.64	14.76	16.64	15.68
ORGANIC CARBON wt%	1.72	1.64	1.76	1.93	1.92	1.89	2.28
IGNITION LOSS wt%	16.94	16.89	15.84	15.75	15.81	17.60	18.10
CARBON wt%	5.79	5.81	5.49	5.65	5.94	6.43	6.56
HYDROGEN wt%	0.16	0.16	0.12	0.13	0.17	0.19	0.18
NITROGEN wt%	0.20	0.21	0.18	0.18	0.23	0.26	0.22
MISCELLANEOUS:							
RETORT DROP in. H_2O/ft	1.53	1.69	1.52	1.53	1.67	2.12	1.30
CARBONATE DECOMP. wt%	31	29	36	37	32	20	26
BED HEIGHT ft.	25.58	25.58	25.58	25.58	25.58	25.58	25.58

* DESIGNATED VALUE SEE TABLE D-1

TEST DATA FROM SEMI-WORKS — DIRECT HEATED

TABLE D-3 (CONT.)

General: Run Number / Test Number		SW-7 PC-2	SW-7 PC-3	SW-7 QC	SW-7 PC-4	SW-7 PC-5	SW-7 PC-6	SW-7 PA-1	SW-7 PA-2	SW-7 PA-3	SW-7 PA-4	SW-7 PB-1	SW-7 PB-2	SW-7 PD
Date		2-22-75	2-23-75	2-24-75	2-26-75	2-27-75	2-28-75	3-1-75	3-2-75	3-4-75	3-5-75	3-8-75	3-9-75	3-10-75
Start Time		0800	0800	0800	0800	0800	0800	2400	0800	1600	0800	1600	0800	2400
Length of Test Hrs		8	16	16	24	24	24	8	24	16	24	16	24	6
Rates and Quantities:														
Top Distributor Gas	SCF/T	1351	1326	1220	1074	1070	1054	1042	1040	1166	1134	1276	1338	1147
Mid Distributor Gas	SCF/T	1524	1513	1533	1469	1501	1469	1440	1456	1076	989	1435	1467	1688
Btm Distributor Gas	SCF/T	14414	14217	14225	13903	13973	13593	13429	13603	14489	14593	12895	12420	15376
Total Gas	SCF/T	17289	17056	16978	16446	16544	16116	15911	16099	16731	16716	15606	15725	18211
Top Distributor Air	SCF/T	3108	3062	3121	2983	3037	2893	2896	2885	3090	3106	987	3290	1688
Mid Distributor Air	SCF/T	1536	1544	1544	1480	1473	1424	1434	1434	1172	1055	2793	1433	3297
Btm Distributor Air	SCF/T	0	0	0	0	0	0	431	433	463	464	420	435	514
Total Air	SCF/T	4644	4616	4665	4463	4510	4317	4761	4752	4725	4625	4200	5158	5499
Shale Throughout	lb/hr/ft^2	408	415	443	426	424	435	435	433	405	404	447	437	370
Temperatures:														
Product Oil	°F	166	151	162	161	164	171	174	175	173	166	168	162	177
Retorted Shale Out	°F	360	359	392	371	375	380	425	431	428	389	339	322	282
Raw Shale In	°F	30	30	30	46	60	50	60	50	45	55	45	40	37
Recycle Gas In	°F	241	239	248	252	252	248	250	256	242	237	256	251	271
Off-Gas	°F	142	144	151	159	161	153	156	163	147	149	176	185	201
Air In	°F	246	249	251	258	256	262	254	259	260	259	253	248	249
Yields:														
Oil Collected	wt% F.A.	95.3	94.5	86.6	89.4	87.4	84.8	85.4	80.5	92.6	87.6	87.7	82.7	96.5
Product Gas (wet)	SCF/T	5062	5001	5275	5154	5097	4778	5300	5331	5092	4794	7227	7461	8802
Retorted Shale	wt% R.S.	83	83	83	82	83	83	83	82	83	83	84	85	84
Liquid Water	lb/ton	11.25	10.14	7.50	9.10	3.89	5.43	12.90	1.50	2.81	6.25	6.42	5.41	1.91
Ash Balance	wt%	100	100	100	100	100	100	100	100	100	100	100	100	100
Atm. N2 Balance	wt%	71	71	74	74	73	72	72	76	69	69	111	93	102
Water Balance	wt%	42	42	42	41	38	36	44	35	45	38	87	69	85
Kerogen Balance	wt%	104	103	105	97	95	92	93	97	99	97	106	114	123
Org. Carbon Balance	wt%	96	91	90	85	88	87	88	92	94	87	90	95	108
Tot. H2 Balance	wt%	103	103	97	94	95	96	100	101	95	95	103	114	121
Org. N2 Balance	wt%	74	77	73	63	70	73	70	78	73	68	58	68	80
Material Recovery	wt%	95	95	95	94	94	93	94	94	95	94	102	100	103
Raw Shale Properties:														
Moisture	wt%	0.93	1.00	0.95	0.92	1.00	1.07	1.10	1.10	1.00	0.84	1.06	1.35	1.23
Fischer Assay	gal/ton	28.7	27.7	30.1	29.0	27.9	27.1	26.6	28.6	29.1	29.0	26.3	26.4	26.4
Fischer Assay Oil	wt%	10.98	10.58	11.48	11.07	10.64	10.34	10.18	10.90	11.10	11.10	10.00	10.10	10.10
Fischer Assay Water	wt%	1.71	1.52	1.45	1.79	1.80	1.66	1.85	1.50	1.50	1.60	1.60	1.80	2.80
Fisher Assay gas+loss	wt%	1.86	2.07	2.38	2.30	2.39	2.49	2.72	1.90	2.60	2.40	2.90	2.50	2.10
Mineral CO_2	wt%	17.39	17.71	17.45	17.49	17.47	17.78	17.65	17.57	17.02	17.43	17.64	18.12	16.73
Ignition Loss	wt%	33.13	32.41	32.49	33.21	33.07	33.01	33.09	33.34	33.26	33.55	32.41	32.13	32.54
Carbon	wt%	17.17	17.34	17.89	18.16	17.07	16.76	16.87	17.53	17.77	17.50	17.29	16.59	17.08
Hydrogen	wt%	1.83	1.83	1.91	1.93	1.81	1.74	1.76	1.83	1.90	1.83	1.82	1.72	1.79
Nitrogen	wt%	0.53	0.55	0.56	0.64	0.54	0.51	0.52	0.53	0.58	0.57	0.59	0.54	0.52
Nominal Part Size	in.	3/4X2 3/4	3/4X2 3/4	3/4X2 3/4	3/4X2 3/4	3/4X2 3/4	3/4X2 3/4	3/4X2 3/4	3/4X2 3/4	3/4X2 3/4	3/4X2 3/4	3/4X2 3/4	3/4X2 3/4	3/4X2 3/4
Collected Oil Properties:														
Gravity Degree	API	21.6	21.5	21.4	20.7	21.0	21.2	21.2	21.0	21.1	21.1	20.7	20.6	19.9
Viscosity SUS @	130° F	92.3	95.2	96.2	121.1	106.4	92.4	91.2	99.2	95.1	95.1	109.9	105.5	134.5
Viscosity SUS @	210° F	42.9	42.3	42.3	44.7	44.7	46.6	47.0	45.6	45.9	46.7	51.0	49.4	52.0
Ramsbottom Carbon	wt%	1.47	1.40	1.16	1.61	1.41	1.48	1.50	1.52	2.14	2.13	1.73	1.81	1.82
Water Content	vol%	0.81	1.48	1.31	0.33	0.65	0.71	0.39	0.40	1.04	1.12	0.39	0.59	0.36
Solids bottom sed.	wt%	1.20	1.39	1.23	0.30	0.44	0.78	0.82	0.63	1.34	1.20	0.60	0.52	0.28
Carbon	wt%	83.55	84.38	84.19	83.15	83.17	83.96	84.36	83.86	84.12	83.71	84.65 *	84.33	84.41
Hydrogen	wt%	11.24	11.89	11.26	11.15	11.13	11.44	11.59	11.23	11.18	11.22	11.49 *	11.40	11.40
Nitrogen	wt%	2.03	2.26	2.11	2.12	2.03	1.98	1.95	2.07	2.01	2.11	2.02 *	1.85	2.13
Product Gas Properties:														
Moisture	vol%	←						20 **						→
Analysis (dry basis)														
H_2	vol%	5.04	5.15	5.41	5.65	5.58	5.43	5.35	4.84	5.19	4.84	5.54	5.58	6.05
N_2	vol%	64.36	64.55	64.34	62.80	63.42	63.82	63.92	66.53	62.97	65.34	63.67	63.55	62.83
O_2	vol%	0.14	0.21	0.64	0.10	0.15	0.14	0.20	0.64	0.13	0.22	0.33	0.36	0.33
CO	vol%	2.45	2.37	2.38	2.57	2.52	2.42	2.37	2.37	2.88	2.57	2.83	3.04	3.08
CH_4	vol%	2.46	2.56	2.70	2.72	2.65	2.58	2.52	2.37	2.24	2.29	2.36	2.19	2.35
CO_2	vol%	22.87	22.40	21.62	23.33	22.87	22.80	22.92	20.70	24.36	22.22	22.88	22.91	22.92
C_2H_4	vol%	0.63	0.64	0.65	0.71	0.72	0.69	0.66	0.60	0.70	0.55	0.68	0.66	0.77
C_2H_6	vol%	0.62	0.65	0.69	0.65	0.64	0.63	0.62	0.59	0.53	0.56	0.55	0.56	0.50
C_3's	vol%	0.71	0.76	0.80	0.76	0.74	0.75	0.76	0.68	0.58	0.75	0.57	0.55	0.56
C_4's	vol%	0.28	0.29	0.33	0.30	0.29	0.27	0.26	0.24	0	0.23	0.16	0.18	0.19
C_5+'s	vol%	←						0.43 *						→
Gross Heat. Value	BTU/SCF	125	129	134	134	132	130	128	120	112	120	120	118	123
Specific Gravity		1.068	1.065	1.059	1.065	1.063	1.064	1.066	1.058	1.072	1.067	1.062	1.063	1.058
Retorted Shale Properties:														
Fischer Assay	gal/ton	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.40	0.90	N/A
Fischer Assay Oil	wt%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fischer Assay Water	wt%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fisher Assay gas+loss	wt%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Mineral CO_2		15.70	16.14	15.67	15.48	16.07	16.17	16.08	15.62	16.44	16.30	15.95	16.28	15.55
Organic Carbon	wt%	2.40	2.17	2.62	2.44	2.22	2.31	2.45	2.73	2.61	2.21	1.89	2.08	4.57
Ignition Loss	wt%	18.40	18.25	18.49	17.53	18.36	18.57	18.47	17.86	19.23	19.18	18.88	19.46	18.74
Carbon	wt%	6.68	6.57	6.89	6.66	6.60	6.72	6.83	6.99	7.09	6.65	6.24 *	6.52	6.84
Hydrogen	wt%	0.18	0.17	0.18	0.17	0.17	0.18	0.19	0.22	0.19	0.17	0.16 *	0.30	0.22
Nitrogen	wt%	0.22	0.24	0.24	0.24	0.23	0.24	0.24	0.25	0.26	0.22	0.20 *	0.25	0.25
Miscellaneous:														
Retort Drop	in. H_2O/ft	1.32	1.33	1.48	1.21	1.16	1.13	1.21	1.21	1.13	1.12	1.43	1.57	1.55
Carbonate Decomp.	wt%	26	24	25	28	24	25	25	27	20	23	24	24	22
Bed Height	ft	25.58	25.58	25.58	25.58	25.58	25.58	25.58	25.58	25.58	25.58	25.58	25.58	25.58

* DESIGNATED VALUES SEE TABLE D-1

TEST DATA FROM SEMI-WORKS — DIRECT HEATED

TABLE D-3 (CONT.)

General:								
Run Number / Test Number		SW-7 PF	SW-7 PF-1	SW-7 PF-2	SW-8 A	SW-8 A-1	SW-8 B	SW-8 B-1
Date		3-11-75	3-12-75	3-13-75	5-6-75	5-8-75	5-10-75	5-11-75
Start Time		2400	0800	1600	0800	0800	0800	0800
Length of Test Hrs		8	24	16	24	24	24	24
Rates and Quantities:								
Top Distributor Gas	SCF/T	998	921	782	887	862	866	851
Mid Distributor Gas	SCF/T	1069	1363	1426	1002	947	945	939
Btm Distributor Gas	SCF/T	13515	13120	13255	13459	12887	13693	13291
Total Gas	SCF/T	15582	15404	15463	15348	14696	15504	15081
Top Distributor Air	SCF/T	3119	2844	2873	2950	2832	2777	2812
Mid Distributor Air	SCF/T	1550	1438	1426	1008	952	931	919
Btm Distributor Air	SCF/T	1051	943	969	740	702	698	699
Total Air	SCF/T	5720	5225	5268	4698	4486	4406	4430
Shale Throughout	$lb/hr/ft^2$	410	452	443	464	486	492	498
Temperatures:								
Product Oil	°F	155	155	161	170	142	150	177
Retorted Shale Out	°F	317	323	367	431	378	344	341
Raw Shale In	°F	30	37	40	74	70	60	57
Recycle Gas In	°F	282	280	273	255	262	272	270
Off Gas	°F	217	211	203	175	182	195	183
Air In	°F	235	239	240	240	254	261	261
Yields:								
Oil Collected	wt%F.A	76.7	79.0	80.9	83.7	83.7	83.9	79.6
Product Gas (wet)	SCF/T	9196	8397	8339	7512	7243	6842	6880
Retorted Shale	wt%R.S	82	83	83	83	84	84	83
Liquid Water	lb/ton	0.87	4.80	5.72	0.66	0.40	2.51	0.53
Ash Balance	wt%	100	100	100	100	100	100	100
Atm N_2 Balance	wt%	102	103	103	109	109	104	101
Water Balance	wt%	94	92	102	70	74	76	66
Kerogen Balance	wt%	101	102	95	98	101	97	95
Org. Carbon Balance	wt%	95	96	91	92	96	94	91
Tot. H_2 Balance	wt%	109	108	106	108	109	105	105
Org. N_2 Balance	wt%	65	73	62	70	76	73	69
Material Recovery	wt%	101	101	101	101	101	100	99
Raw Shale Properties:								
Moisture	wt%	1.07	1.39	1.05	1.19	1.14	0.95	0.89
Fischer Assay	gal/ton	27.1	27.3	27.4	29.4	28.6	28.1	28.3
Fischer Assay Oil	wt%	10.40	10.40	10.50	11.20	10.90	10.70	10.80
Fischer Assay Water	wt%	2.00	1.60	1.70	1.70	1.60	1.40	1.30
Fischer Assay gas+loss	wt%	2.00	2.00	2.20	2.40	2.30	2.60	2.30
Mineral CO_2	wt%	17.44	17.52	16.74	17.83	17.82	17.56	18.11
Ignition Loss	wt%	32.81	32.64	33.00	34.43	33.69	33.81	33.63
Carbon	wt%	16.60	16.92	17.29	17.87	17.42	17.26	17.18
Hydrogen	wt%	1.75	1.80	1.84	1.85	1.80	1.83	1.79
Nitrogen	wt%	0.54	0.54	0.55	0.56	0.53	0.54	0.56
Nominal Part. Size	in.	3/4X2-3/4	3/4X2-3/4	3/4X2-3/4	¼X2-3/4	¼X2-3/4	¼X2-3/4	¼X2-3/4
Collected Oil Properties:								
Gravity Degree	API	20.5	20.1	20.0	21.4	20.9	20.8	20.6
Viscosity SUS @	130° F	132.8	139.7	127.7	99.9	105.1	103.9	107.1
Viscosity SUS @	210° F	51.7	51.7	50.0	46.3	46.2	46.0	47.0
Ramsbottom Carbon	wt%	1.71	1.65	1.76	1.57	1.52	1.58	1.57
Water Content	vol%	0.06	0.19	0.59	0.21	0.20	1.04	0.17
Solids Bottom sed.	wt%	0.61	1.27	2.26	0.07	0.16	0.57	0.69
Carbon	wt%	84.59	84.70	84.54	84.95	84.95	84.65	84.75
Hydrogen	wt%	11.40	11.38	11.36	11.43	11.50	11.42	11.47
Nitrogen	wt%	2.13	2.18	2.11	1.99	1.95	2.00	2.11
Product Gas Properties:								
Moisture	vol%	←			→ 20 * ←			→
Analysis (dry basis)								
H_2	vol%	5.68	5.98	6.01	5.46	5.70	5.71	5.96
N_2	vol%	62.82	63.20	64.03	67.18	66.45	66.37	64.45
O_2	vol%	0.46	0.25	0.12	0.27	0.32	0.35	0.12
CO	vol%	2.86	3.13	2.91	1.74	1.72	1.75	1.81
CH_4	vol%	1.99	2.22	2.19	2.52	2.56	2.64	2.57
CO_2	vol%	24.33	22.96	22.36	19.88	20.28	20.22	21.71
C_2H_4	vol%	0.58	0.71	0.69	0.48	0.49	0.52	0.56
C_2H_6	vol%	0.43	0.49	0.49	0.71	0.72	0.74	0.71
C_3's	vol%	0.43	0.51	0.54	0.77	0.80	0.86	1.07
C_4's	vol%	0	0.13	0.24	0.57	0.52	0.41	0.62
C_5's	vol%	←			→ 0.43 * ←			→
Gross Heat Value	BTU/SCF	104	117	121	135	136	136	148
Specific Gravity		1.068	1.058	1.056	1.051	1.051	1.049	1.059
Retorted Shale Properties:								
Fischer Assay	gal/ton	N/A	N/A	N/A	0.50	0.50	0.50	0.40
Fischer Assay Oil	wt%	N/A	N/A	N/A	0.20	0.20	0.20	0.20
Fischer Assay Water	wt%	N/A	N/A	N/A	0.10	0.10	0.10	0.70
Fischer Assay gas+loss	wt%	N/A	N/A	N/A	0.40	0.50	0.50	0.50
Mineral CO_2	wt%	14.83	15.90	15.90	17.52	17.52	17.47	16.66
Organic Carbon	wt%	2.06	2.34	1.90	1.93	2.29	2.30	2.17
Ignition Loss	wt%	17.49	18.64	18.28	20.17	20.35	20.57	19.27
Carbon	wt%	6.10	6.68	6.24 *	6.71	7.07	7.05	6.71
Hydrogen	wt%	0.18	0.21	0.16 *	0.18	0.19	0.18	0.17
Nitrogen	wt%	0.22	0.26	0.20 *	0.25	0.27	0.26	0.25
Miscellaneous:								
Retort Drop	$in.H_2O/ft$	1.57	1.74	1.58	1.76	1.75	1.97	1.74
Carbonate Decomp.	wt%	30	24	22	19	18	17	24
Bed Height	ft	25.58	25.58	25.58	25.58	25.58	25.58	25.58

* DESIGNATED VALUES SEE TABLE D-1

TEST DATA FROM SEMI-WORKS — DIRECT HEATED

TABLE D-3 (CONT.)

GENERAL:														
RUN NUMBER		SW-8	SW-8	SW-8	SW-9	SW-11	SW-17	SW-17	SW-17	SW-19	SW-19	SW-20	SW-20	SW-20
TEST NUMBER		B-2	B-3	B-4	X	A	I-1	I-2	J	A	A-1	11	A-1	A-2
DATE		5-12-75	5-13-75	5-15-75	5-30-75	8-21-75	10-20-75	10-21-75	10-22-75	10-31-75	11-1-75	11-6-75	11-7-75	11-8-75
START TIME		0800	1600	0800	0800	0800	1600	0800	1600	0800	0800	1700	0800	0800
LENGTH OF TEST HRS.		24	16	16	24	24	16	24	16	24	8	15	24	24
RATES AND QUANTITIES:														
TOP DISTRIBUTOR GAS	SCF/T	856	862	876	717	968	1483	1493	1296	1261	1223	1328	1323	1341
MID DISTRIBUTOR GAS	SCF/T	967	981	967	867	1692	1409	1405	1895	1919	1847	1317	1307	1294
BTM DISTRIBUTOR GAS	SCF/T	13944	12957	13185	12678	12880	12097	12140	13435	11702	11572	11300	11848	11916
TOTAL GAS	SCF/T	15767	14800	15028	14262	15540	14989	15038	16626	14882	14642	13945	14478	14551
TOP DISTRIBUTOR AIR	SCF/T	2891	2796	2815	2592	3126	3359	3436	3130	2943	2869	3664	3622	3686
MID DISTRIBUTOR AIR	SCF/T	962	967	1008	843	1955	1049	1089	1495	1492	1465	815	805	820
BTM DISTRIBUTOR AIR	SCF/T	719	677	684	646	0	0	0	0	0	0	0	0	0
TOTAL AIR	SCF/T	4572	4440	4507	4081	5081	4408	4525	4625	4435	4334	4479	4427	4506
SHALE THROUGHPUT	$lb/hr/ft^2$	481	489	481	618	501	427	416	402	473	484	466	475	463
TEMPERATURES:														
PRODUCT OIL	°F	185	183	176	181	152	145	143	146	144	142	148	146	141
RETORTED SHALE OUT	°F	365	326	336	422	443	380	373	339	400	413	405	387	386
RAW SHALE IN	°F	50	50	68	60	70	60	60	55	55	45	63	50	53
RECYCLE GAS IN	°F	272	269	265	278	249	269	272	263	247	247	253	246	236
OFF-GAS	°F	190	188	181	200	183	161	170	190	153	146	156	156	148
AIR IN	°F	253	261	271	251	269	235	235	219	221	227	195	206	196
YIELDS:														
OIL COLLECTED	wt% F.A.	80.3	81.9	80.3	76.3	84.7	81.1	74.6	79.2	89.9	94.8	85.4	89.6	92.0
PRODUCT GAS (WET)	SCF/T	7073	6877	6916	6252	7070	6816	6942	7235	7292	7067	7129	7098	6799
RETORTED SHALE	wt% R.S.	83	84	81	84	82	82	81	82	82	82	82	81	81
LIQUID WATER	lb/ton	0.56	0.73	0.65	0.30	0.70	1.96	6.43	5.02	6.72	11.38	4.00	7.42	5.23
ASH BALANCE	wt%	100	100	100	101	100	100	99	100	100	100	100	100	99
ATM. N_2 BALANCE	wt%	102	104	99	102	88	84	96	97	100	105	100	102	99
WATER BALANCE	wt%	69	73	75	58	62	99	82	71	87	84	77	64	63
KEROGEN BALANCE	wt%	97	99	89	95	97	90	88	91	100	104	98	100	98
ORG. CARBON BALANCE	wt%	91	92	86	89	92	87	83	86	97	104	92	95	95
TOT. H_2 BALANCE	wt%	103	103	99	96	105	111	98	106	113	114	109	109	100
ORG. N_2 BALANCE	wt%	70	73	67	77	67	61	51	64	66	60	64	70	69
MATERIAL RECOVERY	wt%	100	100	99	99	98	98	98	98	101	102	100	100	99
RAW SHALE PROPERTIES:														
MOISTURE	wt%	0.84	0.71	0.87	0.89	1.19	0.58	0.82	1.53	1.32	0.75	0.94	1.04	0.97
FISCHER ASSAY	gal/ton	28.5	27.8	29.9	28.8	28.3	28.2	28.0	25.0	26.3	26.0	28.6	27.1	27.0
FISCHER ASSAY OIL	wt%	10.90	10.60	11.40	11.00	10.80	10.80	10.70	9.52	10.04	9.90	10.91	10.36	10.29
FISCHER ASSAY WATER	wt%	1.60	1.60	1.50	1.70	1.60	1.80	1.70	2.10	1.73	1.65	1.54	1.71	1.45
FISCHER ASSAY gas + loss	wt%	2.40	2.40	2.50	2.30	2.40	2.00	1.80	1.60	2.14	1.99	2.17	2.20	2.23
MINERAL CO_2	wt%	17.69	17.66	17.32	18.28	17.16	17.95	17.79	17.56	17.42	17.52	17.71	17.84	17.30
IGNITION LOSS	wt%	33.61	33.16	34.58	33.21	33.34	32.90	32.81	32.20	32.76	32.59	33.48	33.24	33.14
CARBON	wt%	17.50	17.14	18.64	17.28	17.25	16.89	16.88	15.96	16.57	16.12	17.45	17.07	17.03
HYDROGEN	wt%	1.84	1.81	1.92	1.84	1.79	1.77	1.77	1.66	1.74	1.75	1.84	1.80	1.90
NITROGEN	wt%	0.57	0.54	0.57	0.50	0.51	0.56	0.64	0.57	0.50	0.53	0.52	0.51	0.49
NOMINAL PART. SIZE	in.	½X2-3/4	½X2-3/4	½X2-3/4	½X2-3/4	½X2-3/4	½X2-3/4	½X2-3/4	½X2-3/4	5/8X2 3/4	5/8X2 3/4	½X2-3/4	½X2-3/4	½X2-3/4
COLLECTED OIL PROPERTIES:														
GRAVITY DEGREE	API	20.5	21.1	21.1	20.5	21.3	20.7	21.0	21.1	21.4	21.5	21.4	21.3	21.4
VISCOSITY SUS @	130°F	119.1	104.7	102.8	115.5	99.0	104.6	97.2	92.4	87.0	98.9	92.1	89.9	94.4
VISCOSITY SUS @	210°F	47.4	45.3	45.6	51.7	49.4	52.2	50.4	49.9	51.4	55.5	50.5	52.4	50.7
RAMSBOTTOM CARBON	wt%	1.45	1.59	1.67	1.83	1.74	2.02	1.84	1.92	1.89	2.38	1.94	2.18	2.32
WATER CONTENT	vol%	0.17	0.38	0.32	0.17	0.34	1.00	0.91	0.23	3.43	3.15	1.93	3.56	2.48
SOLIDS BOTTOM SED.	wt%	0.41	0.32	0.31	0.27	0.13	1.26	0.37	0.17	0.38	0.07	0.83	0.54	0.50
CARBON	wt%	84.80	84.99	84.76	84.66	84.27	85.03	84.89	84.80	83.79	83.80	84.60	84.77	84.84
HYDROGEN	wt%	11.25	11.50	11.47	11.32	11.53	11.43	11.10	11.61	11.52	11.52	11.52	11.53	11.54
NITROGEN	wt%	2.32	2.07	1.89	2.00	1.70	1.98	2.09	2.48	1.95	1.71	1.94	2.12	1.95
PRODUCT GAS PROPERTIES:														
MOISTURE	vol%	←		20 *		→	33.60	25.22	25.42	23.16	20.28	22.34	20.79	18.53
ANALYSIS (DRY BASIS)														
H_2	vol%	5.95	5.40	5.56	5.41	5.19	1.19	0.71	0.83	4.47	4.16	4.87	4.75	4.65
N_2	vol%	64.79	66.58	63.43	65.92	62.33	65.96	65.96	65.43	62.39	63.46	63.75	63.27	63.36
O_2	vol%	0.16	0.35	0.27	0.17	0.33	0.02	0.01	0.01	0	0.08	0	0	0
CO	vol%	1.75	1.79	2.13	1.93	2.69	2.39	1.99	2.68	2.12	1.98	2.31	2.42	2.52
CH_4	vol%	2.38	2.49	2.42	2.46	2.29	2.29	2.30	2.18	2.18	2.28	2.43	2.29	2.31
CO_2	vol%	21.23	20.53	23.43	21.18	24.70	26.28	26.28	26.17	25.83	24.69	23.46	24.29	24.38
C_2H_4	vol%	0.57	0.56	0.63	0.58	0.80	0.71	0.68	0.70	0.91	0.88	0.75	0.76	0.67
C_2H_6	vol%	1.00	0.69	0.62	0.70	0.47	0.57	0.56	0.54	0.61	0.66	0.70	0.62	0.56
C_3's	vol%	1.11	0.79	0.70	0.79	0.58	0.74	0.72	0.68	0.75	0.90	0.90	0.78	0.75
C_4's	vol%	0.63	0.40	0.39	0.44	0.19	0.35	0.33	0.32	0.30	0.50	0.46	0.39	0.37
C_5+'s	vol%	←		0.43 *		→	0.51 *	0.45 *	0.46 *	0.44 *	0.43 *	0.37 *	0.43 *	0.42 *
GROSS HEAT. VALUE	BTU/SCF	152	131	129	133	119	118	111	111	127	135	132	130	126
SPECIFIC GRAVITY		1.059	1.054	1.068	1.058	1.076	1.127	1.129	1.127	1.092	1.091	1.071	1.081	1.081
RETORTED SHALE PROPERTIES:														
FISCHER ASSAY	gal/ton	0.30	0.20	0.80	0.40	0.30	0.20	0.30	0	0.40	0.40	0.20	0.40	0.41
FISCHER ASSAY OIL	wt%	0.10	0.10	0.30	0.10	0.10	0.10	0.10	0	0.14	0.14	0.10	0.16	0.16
FISCHER ASSAY WATER	wt%	0.10	0.30	0.10	0.30	0.40	0.20	0.50	0.20	0.31	0.31	0.10	0.23	0.20
FISCHER ASSAY gas + loss	wt%	0.50	0.10	0.30	0.20	0.40	0.10	0.00	0.10	0.00	0.00	0.10	0.15	0.37
MINERAL CO_2	wt%	16.86	17.12	16.49	17.46	15.12	16.12	15.48	14.63	15.35	15.14	15.89	14.74	15.58
ORGANIC CARBON	wt%	2.02	2.17	2.51	2.32	2.18	1.67	1.70	1.61	2.00	2.06	1.98	2.37	1.93
IGNITION LOSS	wt%	19.32	19.89	19.02	19.52	17.93	17.10	17.03	16.33	17.60	17.36	18.21	17.16	17.49
CARBON	wt%	6.62	6.84	7.01	7.08	6.30	6.07	5.92	5.60	6.19	6.19	6.31	6.39	6.18
HYDROGEN	wt%	0.16	0.18	0.18	0.21	0.18	0.14	0.13	0.15	0.15	0.15	0.18	0.18	0.16
NITROGEN	wt%	0.24	0.26	0.26	0.26	0.23	0.21	0.20	0.22	0.19	0.19	0.19	0.20	0.19
MISCELLANEOUS:														
RETORT DROP	in.H2O/ft	1.64	1.62	1.76	2.37	1.52	1.00	0.91	1.09	1.30	1.31	0.96	1.05	1.05
CARBONATE DECOMP.	wt%	21	19	23	20	28	27	30	32	28	29	27	33	29
BED HEIGHT	ft	25.58	25.58	25.58	25.58	26	25.5	25.5	25.5	25.5	25.5	25.5	25.5	25.5

* DESIGNATED VALUES SEE TABLE D-1

TEST DATA FROM SEMI-WORKS — DIRECT HEATED

TABLE D-3 (CONT.)

GENERAL:							
RUN NUMBER	SW-20	SW-20	SW-20	SW-20	SW-20	SW-20	SW-20
TEST NUMBER	A-3	A-4	A-5	B	B-2	A-6	A-7
DATE	11-9-75	11-10-75	11-11-75	11-12-75	11-13-75	11-13-75	11-14-75
START TIME	0800	0800	0800	2400	0800	2400	0800
LENGTH OF TEST HRS.	24	24	24	8	8	8	24
RATES AND QUANTITIES:							
TOP DISTRIBUTOR GAS SCF/T	1342	1302	1334	1302	1195	1325	1334
MID DISTRIBUTOR GAS SCF/T	1300	1249	1285	1770	1635	1276	1281
BTM DISTRIBUTOR GAS SCF/T	11936	11556	11860	12462	11575	11779	11821
TOTAL GAS	14578	14107	14479	15534	14405	14380	14436
TOP DISTRIBUTOR AIR SCF/T	3745	3730	3867	3724	3488	3856	3717
MID DISTRIBUTOR AIR SCF/T	833	831	864	1686	1593	1155	1112
BTM DISTRIBUTOR AIR SCF/T	0	0	0	0	0	0	0
TOTAL AIR SCF/T	4578	4561	4731	5410	5081	5014	4829
SHALE THROUGHPUT lb/hr/ft^2	459	461	451	438	459	452	462
TEMPERATURES:							
PRODUCT OIL °F	140	139	142	154	145	150	144
RETORTED SHALE OUT °F	402	377	382	378	381	387	385
RAW SHALE IN °F	45	38	39	22	33	39	42
RECYCLE GAS IN °F	235	233	248	254	257	256	257
OFF-GAS °F	147	146	149	164	154	154	152
AIR IN °F	187	189	183	180	195	185	195
YIELDS:							
OIL COLLECTED wt% F.A.	87.5	93.4	89.0	82.2	82.4	83.6	89.6
PRODUCT GAS (WET) SCF/T	7082	6963	7194	8215	7519	7492	7666
RETORTED SHALE wt% R.S.	82	82	81	81	80	81	81
LIQUOR WATER lb/ton	8.59	9.56	9.01	11.92	3.56	5.99	6.49
ASH BALANCE wt%	100	100	99	100	100	99	99
ATM. N_2 BALANCE wt%	103	107	103	94	114	101	103
WATER BALANCE wt%	77	69	74	95	34	60	80
KEROGEN BALANCE wt%	93	107	100	98	94	97	101
ORG. CARBON BALANCE wt%	94	100	96	95	90	96	98
TOT. H_2 BALANCE wt%	99	99	98	111	95	99	109
ORG. N_2 BALANCE wt%	68	66	67	63	63	62	69
MATERIAL RECOVERY wt%	100	102	100	100	98	99	101
RAW SHALE PROPERTIES:							
MOISTURE wt%	0.91	0.77	1.16	0.68	1.04	1.29	0.77
FISCHER ASSAY gal/ton	27.6	26.8	27.8	28.1	28.0	28.9	28.8
FISCHER ASSAY OIL wt%	10.53	10.22	10.58	10.74	10.67	11.04	11.03
FISCHER ASSAY WATER wt%	1.53	1.58	1.70	1.78	1.72	1.58	1.60
FISCHER ASSAY gas + loss wt%	2.18	2.18	2.25	1.68	1.92	2.06	2.20
MINERAL CO_2 wt%	17.72	18.00	17.65	17.58	17.95	17.41	17.40
IGNITION LOSS wt%	33.26	32.68	32.95	33.12	33.20	33.30	33.54
CARBON wt%	17.12	16.86	17.20	16.91	16.91	17.03	17.41
HYDROGEN wt%	1.92	1.89	1.94	1.81	1.81	1.84	1.86
NITROGEN wt%	0.50	0.53	0.49	0.50	0.50	0.50	0.52
NOMINAL PART. SIZE in.	¼X2-3/4	¼X2-3/4	¼X2-3/4	¼X2-3/4	¼X2-3/4	¼X2-3/4	¼X2-3/4
COLLECTED OIL PROPERTIES:							
GRAVITY DEGREE API	21.4	21.3	21.3	21.1	21.1	21.1	21.4
VISCOSITY SUS @ 130°F	89.6	90.3	91.2	94.9	93.1	92.2	91.2
VISCOSITY SUS @ 210°F	50.3	52.1	51.3	47.4	55.5	52.5	48.7
RAMSBOTTOM CARBON wt%	2.23	2.35	2.01	2.18	2.24	1.99	2.07
WATER CONTENT vol%	4.07	4.93	4.22	5.85	1.83	3.89	2.93
SOLIDS BOTTOM SED. wt%	0.53	0.35	0.41	0.47	0.19	0.32	0.63
CARBON wt%	84.82	84.84	85.27	84.55	84.48	83.99	84.26
HYDROGEN wt%	11.51	11.55	11.54	11.40	11.40	11.33	11.40
NITROGEN wt%	2.21	2.06	2.09	2.05	2.05	1.95	2.08
PRODUCT GAS PROPERTIES:							
MOISTURE vol%	17.60	16.41	18.97	21.49	12.60	14.50	19.17
ANALYSIS (DRY BASIS)							
H_2 vol%	4.65	1.23	1.48	4.68	2.20	4.67	4.97
N_2 vol%	63.85	66.28	65.95	62.27	69.63	62.41	63.32
O_2 vol%	0	0	0	0	0.15	0	0
CO vol%	2.48	2.49	2.54	2.78	2.89	2.74	2.62
CH_4 vol%	2.25	2.34	2.38	2.19	2.39	2.24	2.32
CO_2 vol%	24.09	24.73	24.86	25.56	20.13	25.36	23.98
C_2H_4 vol%	0.63	0.67	0.62	0.67	0.67	0.67	0.70
C_2H_6 vol%	0.56	0.62	0.62	0.51	0.55	0.53	0.58
C_3's vol%	0.73	0.84	0.76	0.64	0.70	0.68	0.72
C_4's vol%	0.35	0.39	0.38	0.27	0.31	0.32	0.37
C_5+'s vol%	0.41 *	0.41 *	0.42 *	0.43 *	0.39 *	0.40 *	0.42 *
GROSS HEAT. VALUE BTU/SCF	123	117	116	119	114	120	127
SPECIFIC GRAVITY	1.080	1.115	1.113	1.087	1.078	1.085	1.076
RETORTED SHALE PROPERTIES:							
FISCHER ASSAY gal/ton	0.22	0.32	0.12	0.82	0.26	0.10	0.22
FISCHER ASSAY OIL wt%	0.09	0.12	0.04	0.31	0.10	0.05	0.08
FISCHER ASSAY WATER wt%	0.10	0.14	0.12	0.10	0.05	0.23	0.07
FISCHER ASSAY gas + loss wt%	0.42	0.15	0.26	0	0.16	0.27	0.09
MINERAL CO_2	16.29	15.75	15.98	14.76	14.36	15.17	15.17
ORGANIC CARBON wt%	1.71	1.86	1.80	1.99	1.98	1.86	2.07
IGNITION LOSS wt%	17.49	17.73	17.50	16.50	15.97	17.00	17.43
CARBON wt%	6.15	6.15	6.16	6.01	5.90	6.00	6.21
HYDROGEN wt%	0.16	0.16	0.15	0.15	0.15	0.14	0.15
NITROGEN wt%	0.17	0.19	0.16	0.17	0.17	0.16	0.19
MISCELLANEOUS:							
RETORT DROP in.H_2O/ft	1.04	1.02	0.99	1.03	1.04	0.98	0.99
CARBONATE DECOMP. wt%	25	28	26	32	36	30	30
BED HEIGHT ft	25.5	25.5	25.5	25.5	25.5	25.5	25.5

* DESIGNATED VALUE SEE TABLE D-1

TEST DATA FROM SEMI-WORKS — DIRECT HEATED

TABLE D-3 (CONT.)

GENERAL: RUN NUMBER / TEST NUMBER	SW-20 C-1	SW-20 C-2	SW-20 A-9	SW-20 A-10	SW-20 A-11	SW-20 A-12	SW-20 A-13	SW-20 A-14	SW-20 A-15	SW-20 A-16
DATE	11/15/75	11/18/75	11/20/75	11/22/75	11/23/75	11/24/75	11/25/75	11/26/75	11/27/75	11/28/75
START TIME	1500	2400	0800	0800	0800	0800	0800	0800	0800	0800
LENGTH OF TEST hrs.	17	8	24	24	15	24	24	24	24	24
RATES AND QUANTITIES:										
TOP DISTRIBUTOR GAS SCF/T	1279	1385	1397	1377	1352	1328	1344	1325	1293	1278
MID DISTRIBUTOR GAS SCF/T	1243	1334	1353	1322	1309	1274	1300	1264	1256	1230
BTM DISTRIBUTOR GAS SCF/T	11953	12561	12451	12227	12087	11817	11868	11779	11541	11393
TOTAL GAS SCF/T	14475	15280	15201	14926	14748	14419	14512	14368	14090	13901
TOP DISTRIBUTOR AIR SCF/T	3655	4048	3980	3954	3850	3823	3943	3974	3731	3732
MID DISTRIBUTOR AIR SCF/T	1092	905	885	879	858	855	878	889	834	831
BTM DISTRIBUTOR AIR SCF/T	0	0	0	0	0	0	0	0	0	0
TOTAL AIR SCF/T	4747	4953	4865	4833	4708	4678	4821	4863	4565	4563
SHALE THROUGHPUT $lb/hr/ft^2$	469	426	438	441	449	453	444	441	462	458
TEMPERATURES:										
PRODUCT OIL °F	158	145	142	144	146	138	134	134	134	130
RETORTED SHALE OUT °F	367	344	370	377	386	378	379	380	399	379
RAW SHALE IN °F	45	51	59	27	30	32	34	19	16	27
RECYCLE GAS IN °F	260	183	179	182	186	240	240	239	240	233
OFF-GAS °F	165	153	148	157	151	143	138	136	134	131
AIR IN °F	194	183	179	182	186	183	170	168	178	181
YIELDS:										
OIL COLLECTED wt% F.A.	82.0	104.6	92.7	92.1	96.8	90.7	95.5	99.9	82.2	87.8
PRODUCT GAS (WET) SCF/T	7248	7609	7592	7377	7184	6903	7097	6999	6792	6618
RETORTED SHALE wt% R.S.	81	80	80	81	83	82	83	81	82	84
LIQUID WATER lb/ton	3.73	0.78	3.00	5.08	5.73	10.66	15.29	9.29	15.49	22.30
ASH BALANCE wt%	100	100	99	100	100	100	100	100	100	100
ATM. N_2 BALANCE wt%	102	104	101	102	100	103	104	107	104	108
WATER BALANCE wt%	80	78	88	76	86	66	79	52	60	69
KEROGEN BALANCE wt%	94	101	95	102	108	102	108	104	97	104
ORG. CARBON BALANCE wt%	92	104	95	99	100	95	107	103	92	98
TOT. H_2 BALANCE wt%	103	107	106	111	111	104	111	105	102	103
ORG. N_2 BALANCE wt%	60	79	76	67	75	71	76	72	65	71
MATERIAL RECOVERY wt%	100	101	100	100	101	100	102	100	100	101
RAW SHALE PROPERTIES:										
MOISTURE wt%	0.72	1.24	0.91	0.94	0.95	0.61	0.98	1.09	1.00	1.15
FISCHER ASSAY gal/ton	29.4	28.4	28.0	27.4	26.9	26.5	26.2	27.4	27.7	27.3
FISCHER ASSAY OIL wt%	11.22	10.83	10.68	10.47	10.27	10.13	9.99	10.45	10.55	10.44
FISCHER ASSAY WATER wt%	1.31	1.37	1.45	1.45	1.58	1.73	1.82	1.71	1.91	1.87
FISCHER ASSAY GAS&LOSS wt%	2.20	2.69	2.45	2.22	2.40	2.57	2.17	2.39	2.42	2.17
MINERAL CO_2 wt%	17.78	17.08	17.56	18.08	17.57	18.05	17.77	17.57	17.46	17.14
IGNITION LOSS wt%	33.54	34.05	33.57	32.98	33.24	33.02	32.65	32.57	33.18	33.15
CARBON wt%	17.38	17.85	17.48	16.85	17.09	17.02	16.47	17.27	17.10	17.08
HYDROGEN wt%	1.83	1.93	1.90	1.77	1.83	1.81	1.73	1.81	1.79	1.79
NITROGEN wt%	0.55	0.52	0.51	0.52	0.51	0.51	0.51	0.51	0.51	0.52
NOMINAL PART. SIZE in.	½X2 3/4	+½X2 3/4	+½X2 3/4	+½X2 3/4	+½X2 3/4	+½X2 3/4	+½X2 3/4	+½X2 3/4	+½X2 3/4	+½X2 3/4
COLLECTED OIL PROPERTIES:										
GRAVITY DEGREE API	20.9	21.0	21.2	21.3	21.3	21.3	21.5	21.4	21.5	21.6
VISCOSITY SUS @ 130°F	99.6	94.6	91.8	90.7	91.1	90.6	83.7	87.8	87.2	80.1
VISCOSITY SUS @ 210°F	50.2	52.8	48.4	42.2	42.3	42.4	40.9	42.6	43.1	43.3
RAMSBOTTOM CARBON wt%	1.73	1.51	1.51	1.54	1.42	1.43	1.30	1.34	1.34	1.34
WATER CONTENT vol%	1.84	0.32	1.54	2.37	2.59	5.06	6.85	3.93	7.57	10.01
SOLIDS BOTTOM SED. wt%	0.42	0.25	0.59	0.14	0.75	0.52	0.30	0.29	0.81	0.39
CARBON wt%	84.42	84.56	84.36	84.53	84.67	84.33	84.13	84.54	84.54	84.37
HYDROGEN wt%	11.41	11.65	11.50	11.51	11.51	11.45	11.50	11.45	11.42	11.50
NITROGEN wt%	2.02	2.01	2.01	1.92	2.11	2.00	2.06	1.95	1.68	1.85
PRODUCT GAS PROPERTIES:										
MOISTURE vol%	20.10	16.57	20.47	21.02	22.14	18.12	15.32	12.20	15.45	12.82
ANALYSIS (DRY BASIS)										
H_2 vol%	1.99	2.06	3.64	1.41	1.73	1.32	1.42	1.31	3.50	1.39
N_2 vol%	66.05	64.35	64.45	66.67	66.44	67.45	66.09	66.72	65.60	67.14
O_2 vol%	0	0	0.08	0	0	0.06	0	0	0.04	0
CO vol%	2.84	2.83	2.57	2.58	2.52	2.44	2.64	2.52	2.34	2.59
CH_4 vol%	2.44	2.32	2.13	2.34	2.45	2.36	2.37	2.27	2.25	2.36
CO_2 vol%	23.85	25.80	24.44	24.12	23.87	23.42	24.67	24.46	23.45	23.67
C_2H_4 vol%	0.69	0.63	0.63	0.68	0.69	0.69	0.65	0.64	0.64	0.69
C_2H_6 vol%	0.60	0.56	0.56	0.61	0.63	0.61	0.59	0.58	0.58	0.60
C_3's vol%	0.77	0.69	0.73	0.77	0.81	0.79	0.77	0.74	0.80	0.78
C_4's vol%	0.35	0.33	0.34	0.39	0.42	0.45	0.41	0.38	0.40	0.41
C_5+'s vol%	0.43 *	0.41 *	0.43 *	0.43 *	0.44 *	0.42 *	0.40 *	0.39 *	0.40 *	0.39 *
GROSS HEAT. VALUE BTU/SCF	120	114	119	118	123	119	116	111	122	116
SPECIFIC GRAVITY	1.102	1.111	1.092	1.110	1.106	1.107	1.112	1.111	1.087	1.106
RETORTED SHALE PROPERTIES:										
FISCHER ASSAY gal/ton	0.40	0.60	0.27	0.17	0.40	0.20	0.31	0.24	0.12	0.51
FISCHER ASSAY OIL wt%	0.15	0.23	0.11	0.06	0.15	0.08	0.12	0.09	0.04	0.19
FISCHER ASSAY WATER wt%	0.27	0.09	0.10	0.16	0.24	0.25	0.34	0.50	0.30	0.49
FISCHER ASSAY GAS&LOSS wt%	0.12	0.04	0.22	0.38	0.20	0.18	0.27	0.08	0.18	0.14
MINERAL CO_2 wt%	15.91	15.72	16.16	15.78	16.18	15.74	16.57	15.83	15.53	16.18
ORGANIC CARBON wt%	1.86	1.69	1.58	1.85	1.83	2.05	2.04	2.00	2.24	2.37
IGNITION LOSS wt%	17.82	17.15	17.34	17.35	17.70	17.72	18.40	17.71	18.05	19.24
CARBON wt%	6.20	5.98	5.99	6.15	6.24	6.34	6.56	6.32	6.48	6.78
HYDROGEN wt%	0.15	0.13	0.15	0.16	0.17	0.18	0.19	0.16	0.19	0.19
NITROGEN wt%	0.18	0.23	0.24	0.20	0.21	0.22	0.23	0.21	0.23	0.24
MISCELLANEOUS:										
RETORT DROP in. H_2O/ft	1.00	0.94	0.88	1.12	0.94	1.00	1.06	1.01	1.00	1.09
CARBONATE DECOMP. wt%	27	26	26	29	24	29	22	27	27	21
BED HEIGHT ft	25.5	25.5	25.5	25.5	25.5	25.5	25.5	25.5	25.5	25.5

* DESIGNATED VALUES SEE TABLE D-1

TEST DATA FROM SEMI-WORKS — INDIRECT HEATED

TABLE D-4

General:														
Run Number		SW-21	SW-22	SW-22	SW-23	SW-23	SW-23	SW-23	SW-23	SW-23	SW-23	SW-23	SW-23	SW-23
Test Number		A	A-1	A-2	A-1	A-2	A-3	A-4	A-5	A-6	A-7	B-1	B-2	A-8
Date		12-13-75	12-19-75	12-20-75	1-16-76	1-17-76	1-18-76	1-19-76	1-20-76	1-21-76	1-22-76	1-23-76	1-24-76	1-25-76
Start Time		0000	2400	0800	0800	0800	0800	0800	0800	2400	1600	1600	0800	1600
Length of Test	Hrs	24	8	8	24	24	24	24	24	24	8	16	12	16
Rates and Quantities:														
Top Distributor Gas	SCF/T	12350	16523	15804	18540	18251	19046	18763	18721	18252	16791	17576	17722	19541
Mid Distributor Gas	SCF/T	0	0	0	0	0	0	0	0	0	0	0	0	0
Btm Distributor Gas	SCF/T	3300	4271	3750	5037	4886	5119	5043	4962	4809	8395	6818	6833	5237
Total Gas	SCF/T	15650	20794	19554	23577	23127	24165	23806	23683	23061	25186	24394	24555	24778
Shale Throughout	$lb/hr/ft^2$	438	348	364	344	339	324	329	324	329	316	322	324	310
Hot Gas Above 77°F	MBTU/T	488	549	478	588	582	611	595	584	566	541	578	564	629
Temperatures:														
Product Oil	°F	158	171	176	175	175	175	172	174	170	170	140	160	150
Retorted Shale Out	°F	550	NA	NA	545	550	555	559	528	561	439	475	490	499
Raw Shale In	°F	30	25	25	26	36	35	40	40	40	40	60	50	50
Product Gas	°F	241	213	222	222	224	224	219	216	216	211	214	205	235
Off Gas	°F	225	277	294	305	292	297	302	299	295	301	305	293	286
Top Heater Out	°F	1110	1110	1080	1190	1190	1190	1190	1180	1190	1190	1200	1200	1200
Top Distributor In	°F	1080	1084	1040	1142	1148	1148	1151	1143	1148	1136	1146	1141	1133
Btm Distributor In	°F	241	213	222	222	224	224	219	216	216	211	214	205	235
Yields:														
Oil Collected	wt%	71.0	86.5	78.9	93.7	30.8	81.7	79.1	91.2	91.1	106.8	88.4	90.9	92.4
Total Oil C_5	wt% F.A.	72.3	88.7	80.1	96.1	83.6	84.8	81.8	93.3	92.6	109.6	91.7	94.0	95.5
Product Gas (wet)	SCF/T	884	1140	1130	1440	1260	1690	1720	1370	1380	1560	1650	1690	1660
Retorted Shale	wt% R.S.	86	87	89	84	86	85	85	85	84	86	86	86	86
Liquid Water	lb/ton	4.95	45.4	14.0	42.6	33.9	29.7	45.1	25.3	21.2	4.4	23.7	7.8	22.8
Ash Balance	wt%	99	100	100	101	101	100	100	100	99	100	100	100	100
Water Balance	wt%	39	147	73	157	145	105	133	108	89	55	86	76	95
Kerogen Balance	wt%	87	94	107	78	89	95	95	96	88	109	106	101	101
Org. Carbon Balance	wt%	87	90	102	88	85	88	86	93	88	105	95	96	97
Org. H_2 Balance	wt%	95	102	111	104	94	99	96	99	100	122	105	104	108
Org. N_2 Balance	wt%	84	74	90	97	95	92	93	93	102	101	102	103	101
Material Recovery	wt%	96	100	100	99	100	100	100	100	98	100	101	100	100
Raw Shale Properties:														
Moisture	wt%	1.12	1.03	1.02	1.12	0.94	1.17	1.13	1.03	1.15	1.43	1.38	1.25	1.40
Fischer Assay	gal/ton	30.1	26.9	28.8	27.4	28.3	27.3	28.3	28.6	27.	27.5	27.9	27.9	27.1
Fischer Assay Oil	wt%	11.51	10.28	10.97	10.46	10.81	10.67	10.79	10.90	10.32	10.50	10.63	10.66	10.33
Fischer Assay Water	wt%	1.55	1.38	1.39	1.82	1.42	1.81	1.94	1.69	1.92	2.17	1.81	1.64	1.91
Fischer Assay, gas+loss	wt%	2.15	1.88	1.98	1.53	1.94	1.78	1.84	1.18	1.97	1.85	1.99	2.08	2.37
Mineral CO_2	wt%	17.25	17.60	17.58	18.26	18.1	17.23	17.05	17.51	17.74	16.48	17.16	17.30	17.42
Ignition Loss	wt%	34.20	33.25	33.78	33.01	32.95	32.88	33.38	33.27	32.89	33.54	33.05	33.02	33.62
Carbon	wt%	17.98	17.66	17.64	16.85	17.17	16.96	17.45	17.27	16.80	17.08	17.30	17.08	17.05
Hydrogen	wt%	1.91	1.79	1.82	1.73	1.81	1.78	1.84	1.82	1.76	1.75	1.80	1.73	1.78
Nitrogen	wt%	0.55	0.57	0.56	0.45	0.48	0.49	0.5	0.51	0.45	0.51	0.49	0.48	0.50
Nominal Part Size	in.	½ x 2	½ x 2	½ x 2	½ x 2	½ x 2	½ x 2	½ x 2	½ x 2	½ x 2	½ x 2	½ x 2	½ x 2	½ x 2
Collected Oil Properties:														
Gravity Degree	API	23.5	23.0	21.1	20.3	20.2	19.8	19.9	20.3	21.0	20.1	19.7	20.1	20.4
Viscosity SUS @	130°F	62.0	105.1	92.8	105.9	106.0	112.8	94.9	111.9	112.4	112.9	106.6	115.4	102.4
Viscosity SUS @	210°F	42.5	46.7	47.4	50.4	52.1	53.0	49.1	53.1	53.0	53.4	51.7	56.5	50.5
Ramsbottom Carbon	wt%	1.40	1.25	1.27	1.77	1.81	2.00	2.24	2.26	2.44	2.41	2.42	2.59	1.71
Water Content	vol%	2.67	13.0	6.15	15.53	14.55	12.89	18.58	9.56	8.15	0.18	10.28	3.57	9.27
Solids Bottom Sed.	wt%	0.25	0.91	0.94	1.62	1.72	1.47	3.04	2.14	1.31	0.13	2.01	2.36	0.85
Carbon	wt%	84.66	84.82	84.22	83	84.47	84.48	84.39	84.51	84.56	84.35	84.23	83.87	84.65
Hydrogen	wt%	11.56	11.66	11.47	11.38	11.45	11.48	11.48	11.50	11.47	11.49	11.28	11.33	11.36
Nitrogen	wt%	1.74	1.62	1.76	1.98	2.04	2.01	1.97	1.95	1.97	1.98	1.89	1.84	1.88
Product Gas Properties:														
Moisture	vol%	30.63	23.50	28.50	31.34	29.85	27.30	25.80	32.00	32.00	31.10	26.50	32.00	30.00
Analysis (dry basis)														
H_2	vol%	25.00	24.48	24.61	25.54	26.73	27.16	26.87	26.10	26.23	27.47	26.68	26.68	26.18
N_2	vol%	2.04	6.96	9.78	1.69	1.66	1.17	1.11	1.33	0.80	0.75	0.79	0.68	0.96
O_2	vol%	0	0.01	0.01	0.01	0.01	0	0.05	0	0.01	0	0	0	0
CO	vol%	2.15	2.72	2.58	4.63	4.13	3.91	4.09	3.75	4.24	3.24	3.81	3.88	4.14
CH_4	vol%	25.54	21.47	19.37	19.26	19.15	18.72	18.30	19.08	19.13	20.72	20.20	19.67	19.92
CO_2	vol%	13.78	16.22	15.91	28.69	28.63	29.68	30.68	29.62	28.98	25.49	27.63	27.81	27.34
C_2H_4	vol%	8.93	4.13	3.76	4.33	4.38	4.02	3.90	4.64	4.36	4.84	4.76	4.73	4.61
C_2H_6	vol%	7.96	7.46	6.72	5.32	5.09	5.07	4.93	5.03	5.16	5.71	5.25	5.29	5.46
C_3's	vol%	7.45	7.25	6.52	4.08	3.88	3.90	3.81	4.02	4.02	4.56	4.00	4.16	4.24
C_4's	vol%	3.00	4.13	3.76	1.60	1.50	1.57	1.44	1.51	1.61	1.81	1.44	1.70	1.73
H_2S	vol%	4.16	5.18	6.98	1.95	1.94	1.93	1.92	1.97	1.71	1.69	1.70	1.68	1.70
NH_3	vol%	N/A	N/A	N/A	2.90	2.91	2.87	2.87	2.94	3.75	3.72	3.73	3.72	3.73
Gross Heat. Value	BTU/SCF	951	862	803	644	633	627	612	637	642	697	655	663	669
Specific Gravity		0.808	0.857	0.857	0.859	0.846	0.851	0.864	0.858	0.851	0.820	0.833	0.840	0.842
Retorted Shale Properties:														
Fischer Assay	gal/ton	3.2	1.0	5.3	0.25	0.30	0.40	0.40	0.30	0.30	0.20	0.40	0.30	0.50
Fischer Assay Oil	wt%	1.24	0.37	2.01	0.08	0.11	0.15	0.14	0.12	0.11	0.09	0.13	0.11	0.19
Fischer Assay Water	wt%	0.41	0.36	0.51	0.40	0.32	0.30	0.28	0.28	0.28	0.41	0.36	0.34	0.34
Fischer Assay, gas+loss	wt%	0.22	0.38	0.53	0.02	0.33	0.10	0.09	0.17	0.14	0.14	0.10	0.14	0.20
Mineral CO_2	wt%	18.54	19.30	18.87	15.42	18.39	18.58	19.01	18.54	18.11	18.51	18.59	19.02	18.99
Organic Carbon	wt%	4.35	3.14	5.34	2.75	2.43	2.36	2.62	2.74	2.38	2.69	2.94	2.69	2.76
Ignition Loss	wt%	23.90	22.46	25.23	28.4	20.83	20.84	21.25	21.28	20.29	21.32	21.79	21.31	21.77
Carbon	wt%	9.41	8.41	10.49	6.96	7.45	7.43	7.80	7.80	7.32	7.74	8.01	7.88	7.94
Hydrogen	wt%	0.47	0.32	0.60	0.19	0.22	0.20	0.21	0.21	0.20	0.20	0.22	0.21	0.24
Nitrogen	wt%	0.37	0.32	0.40	0.23	0.26	0.25	0.27	0.27	0.25	0.26	0.28	0.28	0.29
Miscellaneous:														
Retort Drop	in. H_2O/ft	0.50	0.46	0.38	0.56	0.57	0.6	0.57	0.57	0.60	0.79	0.58	0.63	0.53
Carbonate Decomp.	wt%	8	6	5	30	14	9	6	10	15	5	7	6	7
Bed Height	ft	24	24	24	24	24	24	24	24	24	24	24	24	24

TEST DATA FROM SEMI-WORKS — INDIRECT HEATED

TABLE D-4 (CONT.)

General: Run Number / Test Number	SW-23 B-5	SW-23 C-1	SW-22 C-2.1	SW-23 C-2.2	SW-23 C-2.3	SW-23 C-5
Date	2-1-76	2-2-76	2-3-76	2-4-76	2-5-76	2-7-76
Start Time	1600	1600	2400	0800	1600	1600
Length of Test Hrs	24	16	8	24	15	16
Rates and Quantities:						
Top Distributor Gas SCF/T	14913	14065	12783	12115	12544	11751
Mid Distributor Gas SCF/T	0	0	0	0	0	0
Btm Distributor Gas SCF/T	7671	7870	8671	8332	8558	8433
Total Gas SCF/T	22584	21935	21454	20447	21102	20184
Shale Throughout $lb/hr/ft^2$	408	436	492	509	501	529
Hot Gas Above 77°F MBU/T	508	496	465	429	466	442
Temperatures:						
Product Oil °F	187	150	195	160	189	182
Retorted Shale Out °F	452	450	398	411	396	414
Raw Shale In °F	40	40	50	40	50	40
Product Gas °F	221	220	200	209	205	215
Off Gas °F	339	332	326	303	322	308
Top Heater Out °F	1200	1230	1260	1200	1242	1250
Top Distributor In °F	1151	1183	1206	1153	1198	1206
Btm Distributor In °F	150	150	150	150	150	152
Yields:						
Oil Collected wt%	81.8	86.0	88.0	87.3	93.5	85.8
Total Oil C_5+wt% F.A.	84.1	88.0	89.6	88.9	95.3	88.3
Product Gas (wet) SCF/T	1081	1070	890	940	950	1175
Retorted Shale wt% R.S	86	86	85	86	88	87
Liquid Water lb/ton	34.4	28.9	32.4	27.8	37.8	32.2
Ash Balance wt%	100	100	99	100	100	101
Water Balance wt%	137	91	106	118	124	101
Kerogen Balance wt%	89	92	82	94	101	103
Org.Carbon Balance wt%	86	90	83	90	93	97
Org.H_2 Balance wt%	93	96	92	96	102	107
Org.N_2 Balance wt%	93	88	92	92	97	100
Material Recovery wt%	99	99	98	100	101	101
Raw Shale Properties:						
Moisture wt%	0.90	1.05	0.94	0.78	0.84	1.19
Fischer Assay gal/ton	29.8	28.6	27.5	28.7	26.1	29.65
Fischer Assay Oil wt%	11.36	10.93	10.48	10.97	9.94	11.33
Fischer Assay Water wt%	1.39	1.59	1.81	1.68	1.88	1.67
Fischer Assay gas+loss wt%	1.90	2.07	2.10	2.22	1.78	2.27
Mineral CO_2 wt%	16.39	17.13	18.41	17.62	17.65	16.95
Ignition Loss wt%	33.85	33.41	33.06	33.77	33.25	33.75
Carbon wt%	17.82	17.41	17.35	17.75	17.44	17.64
Hydrogen wt%	1.87	1.84	1.82	1.87	1.83	1.85
Nitrogen wt%	0.50	0.49	0.48	0.49	0.48	0.51
Nominal Part. Size wt%	½ x 2	½ x 2	½ x 2	½ x 2	½ x 2	½ x 2
Collected Oil Properties:						
Gravity Degree API	19.8	19.9	19.0	20.2	21.0	20.5
Viscosity SUS @ 130°F	111.0	117.4	105.0	88.5	85.4	89.5
Viscosity SUS @ 210°F	53.9	53.1	58.0	51.4	49.1	48.9
Ramsbottom Carbon wt%	2.16	1.98	2.21	1.61	1.52	1.34
Water Content vol%	7.10	4.65	2.16	4.16	2.77	1.75
Solids Bottom Sed. wt%	3.35	3.40	2.30	2.61	1.27	0.95
Carbon wt%	84.65	84.99	84.58	84.88	85.15	85.17
Hydrogen wt%	11.34	11.41	11.31	11.42	11.42	11.44
Nitrogen wt%	2.02	1.88	2.00	1.92	1.99	1.98
Product Gas Properties:						
Moisture vol%	29.10	27.00	29.30	28.10	29.90	29.40
Analysis (dry basis)						
H_2 vol%	27.91	27.33	25.14	27.06	25.53	25.58
N_2 vol%	0.80	0.57	1.34	0.91	0.55	0.61
O_2 vol%	0	0	0	0	0	0
CO vol%	3.26	3.21	3.24	2.94	2.44	2.78
CH_4 vol%	23.80	24.51	26.19	25.40	25.92	26.60
C_2H_4 vol%	20.92	20.32	18.96	16.96	16.73	17.11
C_2H_6 vol%	5.95	7.00	7.99	7.45	9.58	9.24
C_2's vol%	6.62	6.61	6.67	7.16	7.34	7.11
C_3's vol%	5.38	5.25	5.13	6.18	6.27	5.69
C_4's vol%	2.12	1.94	1.82	2.65	2.34	2.00
H_2S vol%	2.30	2.32	2.32	2.33	2.33	2.33
NH_3 vol%	0.94	0.96	1.21	0.96	0.96	0.96
Gross Heat. Value BTU/SCF	786	799	819	870	898	870
Specific Gravity	0.798	0.795	0.797	0.788	0.796	0.787
Retorted Shale Properties:						
Fisher Assay gal/ton	0.27	0.30	0.30	0.20	0.60	0.40
Fischer Assay Oil wt%	0.10	0.12	0.12	0.09	0.25	0.17
Fischer Assay Water wt%	0.50	0.27	0.63	0.74	0.63	0.69
Fischer Assay gas+loss wt%	0	0.05	0.14	0.22	0.49	0.27
Mineral CO_2 wt%	18.94	19.67	19.07	19.25	19.82	20.03
Organic Carbon wt%	2.84	2.55	2.38	2.99	3.14	3.16
Ignition Loss wt%	22.22	22.02	21.07	22.72	23.19	23.20
Carbon wt%	8.01	7.91	7.58	8.24	8.55	8.62
Hydrogen wt%	0.27	0.25	0.23	0.27	0.34	0.34
Nitrogen wt%	0.31	0.28	0.29	0.30	0.31	0.35
Miscellaneous:						
Retort Drop in. H_2O/ft	0.99	1.08	1.24	1.21	1.42	1.27
Carbonate Decomp. wt%	2	2	13	6	2	2
Bed Height ft	24	24	24	24	24	24

TEST DATA FROM SEMI-WORKS — INDIRECT HEATED

TABLE D-4 (CONT.)

GENERAL: RUN NUMBER / TEST NUMBER	SW-28 C-1	SW-28 C-2	SW-28 STEP3	SW-28 A-3	SW-28 A-4	SW-28 A-4.1	SW-28 A-4.2	SW-28 A-4.3	SW-28 A-4.4	SW-31 B	SW-31 D
DATE	3/14/76	3/15/76	3/16/76	3/17/76	3/18/76	3/19/76	3/20/76	3/21/76	3/22/76	4/3/76	4/4/76
START TIME	0800	0800	1600	1200	1600	2000	0800	0800	0800	2000	1800
LENGTH OF TEST hrs.	24	22	14	24	16	12	24	24	8	12	14
RATES AND QUANTITIES:											
TOP DISTRIBUTOR GAS SCF/T	12181	11467	8693	8463	9524	11058	10270	9659	9541	10887	10187
MID DISTRIBUTOR GAS SCF/T	0	0	0	0	2076	0	0	0	0	0	0
BTM DISTRIBUTOR GAS SCF/T	8011	7700	9973	11051	8923	12572	11647	10998	10850	8766	9807
TOTAL GAS SCF/T	20192	19167	18666	19514	20503	23630	21917	20657	20301	19653	19994
SHALE THROUGHPUT lb/hr/ft²	433	461	480	465	458	401	421	448	460	464	456
HOT GAS ABOVE 77°F MBTU/T	451	429	326	318	358	415	393	369	359	405	382
TEMPERATURES:											
PRODUCT OIL °F	147	170	153	150	175	149	147	147	152	158	158
RETORTED SHALE OUT °F	355	380	337	295	336	308	312	349	361	362	336
RAW SHALE IN °F	40	40	41	41	52	40	40	40	40	50	50
PRODUCT GAS °F	217	217	228	220	209	212	214	215	217	221	219
OFF-GAS °F	311	302	256	250	294	333	322	294	325	277	281
TOP HEATER OUT °F	1264	1245	1341	1370	1380	1378	1380	1388	1380	1300	1370
TOP DISTRIBUTOR IN °F	1197	1197	1268	1288	1300	1298	1299	1301	1301	1222	1285
BTM DISTRIBUTOR IN °F	150	150	150	150	150	150	150	150	150	152	151
YIELDS:											
OIL COLLECTED wt%	89.3	87.0	59.9	58.9	83.9	94.2	93.2	78.2	68.3	77.2	78.1
TOTAL OIL C_5+ wt%F.A.	91.3	88.4	60.4	60.1	85.4	94.9	94.0	79.7	69.5	80.2	79.3
PRODUCT GAS (WET) SCF/T	1072	887	203	586	751	566	516	616	610	1344	567
RETORTED SHALE wt%R.S.	87	87	88	89	91	90	89	88	89	88	89
LIQUID WATER lb/ton	43.5	22.5	23.4	18.3	18.5	29.2	30.2	30.0	17.6	20.2	20.6
ASH BALANCE wt%	100	100	100	100	100	100	100	100	100	100	100
WATER BALANCE wt%	93	61	59	56	57	74	81	97	67	117	75
KEROGEN BALANCE wt%	106	96	72	84	108	111	104	89	94	100	90
ORG. CARBON BALANCE wt%	96	90	74	82	96	103	96	84	89	97	87
ORG. H_2 BALANCE wt%	105	96	83	91	106	103	99	87	93	107	92
ORG. N_2 BALANCE wt%	103	88	87	109	98	112	111	98	98	89	91
MATERIAL RECOVERY wt%	101	99	95	97	100	101	100	98	99	100	98
RAW SHALE PROPERTIES:											
MOISTURE wt%	1.35	1.24	1.05	1.24	1.09	1.05	1.32	1.25	1.19	0.89	0.87
FISCHER ASSAY gal/ton	27.9	28.7	27.1	27.2	25.3	25.7	26.6	27.3	28.2	26.7	27.0
FISCHER ASSAY OIL wt%	10.63	10.75	10.36	10.39	9.65	9.78	10.14	10.44	11.28	10.14	10.29
FISCHER ASSAY WATER wt%	2.02	1.83	1.88	1.44	1.78	1.96	1.54	1.33	1.26	1.24	1.46
FISCHER ASSAY GAS&LOSS wt%	2.04	2.10	1.86	2.14	1.90	1.96	2.07	2.13	1.84	1.96	1.87
MINERAL CO_2 wt%	17.81	17.29	17.89	18.15	17.92	17.93	17.59	17.44	17.54	17.31	17.67
IGNITION LOSS wt%	33.81	34.61	34.74	34.02	33.11	31.76	32.15	33.12	33.65	31.92	32.53
CARBON wt%	17.66	18.36	18.26	17.89	16.60	15.68	16.40	17.64	18.31	16.42	16.68
HYDROGEN wt%	1.87	1.97	1.89	1.91	1.72	1.70	1.70	1.85	1.93	1.72	1.74
NITROGEN wt%	0.50	0.58	0.56	0.51	0.48	0.45	0.45	0.48	0.53	0.54	0.54
NOMINAL PART. SIZE in.	+½"X2"	+½"X2"	+½"X2"	+½"X2"	+½"X2"	+½"X2"	+½"X2"	+½"X2"	+½"X2"	+½"X2"	+½"X2"
COLLECTED OIL PROPERTIES:											
GRAVITY DEGREE API	21.7	22.0	21.9	21.8	21.8	20.6	20.0	21.2	20.9	22.0	21.7
VISCOSITY SUS @ 130°F	68.4	66.8	63.4	63.5	64.6	82.9	86.1	72.2	71.5	67.0	68.2
VISCOSITY SUS @ 210°F	42.2	41.6	41.4	42.5	41.8	45.0	46.1	44.1	44.7	41.9	42.1
RAMSBOTTOM CARBON wt%	1.33	1.28	1.16	0.95	1.11	1.60	2.10	1.34	1.74	1.11	1.41
WATER CONTENT vol%	1.42	1.92	8.74	1.52	4.76	1.34	0.93	1.06	0.74	0.97	0.39
SOLIDS BOTTOM SED. wt%	0.65	0.54	1.49	0.75	0.83	1.27	1.70	1.43	0.94	0.18	0.09
CARBON wt%	84.70	84.67	84.67	84.61	84.65	85.00	84.84	84.82	84.69	83.62	84.12
HYDROGEN wt%	11.51	11.47	11.44	11.46	11.59	11.45	11.44	11.48	11.53	11.63	11.66
NITROGEN wt%	2.13	2.08	2.06	1.95	1.91	2.07	2.01	1.90	2.08	1.99	2.13
PRODUCT GAS PROPERTIES:											
MOISTURE vol%	21.98	19.01	35.28	31.17	34.05	28.85	28.80	33.20	32.60	33.25	33.25
ANALYSIS (DRY BASIS)											
H_2 vol%	25.31	24.35	24.02	24.13	24.76	25.49	24.92	24.66	24.16	25.11	25.22
N_2 vol%	0.76	1.98	0.74	0.96	0.40	0.61	0.53	0.76	1.14	0.37	0.61
O_2 vol%	0.04	0.14	0.09	0.01	0	0	0	0	0	0	0
CO vol%	2.40	2.45	2.34	2.67	2.97	2.76	2.72	2.62	2.60	2.69	3.17
CH_4 vol%	25.94	26.43	29.34	31.40	31.06	32.52	31.94	33.49	33.85	27.75	29.63
CO_2 vol%	16.36	15.48	16.14	15.22	14.76	15.46	15.13	13.88	13.79	17.46	19.12
C_2H_4 vol%	9.47	9.25	13.05	12.79	13.20	12.80	12.70	12.81	12.97	10.00	11.15
C_2H_6 vol%	7.37	7.36	4.97	4.65	4.85	4.41	4.58	4.27	4.20	7.46	4.76
C_3's vol%	5.68	5.85	3.71	2.88	2.70	2.18	2.38	2.35	2.29	5.63	2.79
C_4's vol%	2.20	2.27	1.04	0.74	0.78	0.58	0.61	0.61	0.48	1.84	0.92
H_2S vol%	3.26	3.22	3.32	3.30	3.30	1.94	3.26	3.31	3.29	1.16	1.83
NH_3 vol%	1.22	1.21	1.25	1.24	1.24	1.24	1.22	1.24	1.23	0.54	0.79
GROSS HEAT. VALUE BTU/SCF	884	888	841	823	829	803	811	822	819	833	778
SPECIFIC GRAVITY	0.792	0.796	0.762	0.739	0.732	0.71[illegible]	0.725	0.713	0.714	0.786	0.758
RETORTED SHALE PROPERTIES:											
FISCHER ASSAY gal/ton	0.43	1.27	7.60	7.20	5.30	0.52	0.49	1.71	5.90	2.30	2.55
FISCHER ASSAY OIL wt%	0.16	0.49	2.92	2.74	2.02	0.20	0.19	0.65	2.26	0.88	0.97
FISCHER ASSAY WATER wt%	0.77	0.56	0.72	0.66	0.61	0.84	0.69	0.80	0.69	0.54	0.67
FISCHER ASSAY GAS&LOSS wt%	0.06	0.25	0.38	1.11	0.61	0.64	0.61	0.40	0.59	0.52	0.49
MINERAL CO_2 wt%	20.23	19.62	18.71	18.43	19.43	19.55	19.43	19.74	19.35	18.12	19.05
ORGANIC CARBON wt%	3.30	3.79	5.52	5.93	4.16	3.10	3.04	3.74	5.51	3.76	3.63
IGNITION LOSS wt%	23.77	24.04	25.27	24.85	25.50	23.32	23.32	23.84	25.45	22.72	23.31
CARBON wt%	8.82	9.14	10.62	10.96	9.46	8.43	8.34	9.12	10.79	8.87	8.83
HYDROGEN wt%	0.33	0.38	0.72	0.82	0.53	0.34	0.32	0.42	0.68	0.45	0.42
NITROGEN wt%	0.34	0.35	0.41	0.48	0.34	0.34	0.34	0.35	0.39	0.36	0.36
MISCELLANEOUS:											
RETORT DROP in. H_2O/ft	1.09	1.04	0.94	0.94	1.08	1.42	1.43	1.41	1.10	0.78	0.79
CARBONATE DECOMP wt%	1.35	2.26	8.64	9.67	2.68	2.96	2.29	0.60	1.31	4.75	5.11
BED HEIGHT ft	24.5	24.5	24.5	24.5	24.5	24.5	24.5	24.5	24.5	24.5	24.5

APPENDIX E

EQUIPMENT SUMMARY LIST

Feed Preparation

Primary Crusher
36" x 42" Traylor Bulldog, Blake-Type Jaw Crusher, 100 HP, -5" setting 40 TPH capacity

Secondary Crusher
Allis-Chalmers Toothed Double Roll Crusher, 25 HP each roll, 1 3/4" Tooth to roll setting, 38 TPH capacity

Pilot Plant Retort System

Raw Shale Weighbelt
Ramsey Model 10-11" Vey-R-Weigh" Conveyor Scale System for 24" wide conveyor to handle 4 TPH of shale weighing 85-90 lbs per cu. ft. at a speed of 8.5 fpm (15.7 lbs per foot)

Retort
Vertical cylindrical vessel, 4'-6" O.D., 2'-6" I.D. approximately 33' high with 1/4" carbon steel shell, design pressure 10 psig. Retort lining consists of one layer of 1/8" Kaiser Fiberfrac insulating felt, 7 1/2" of Kaiser Celocast 20 insulating castable and 4 1/2" vertical course of Kaiser Aztex fire clay brick. One top and two bottom Salina Model MFS 1716 rotary gas seals.

Coalescer
Vertical cylindrical vessel approximately 7' high, 30" O.D. with internal pipes of 20" and 10" for gas flow directional changes and optional oil sprays in inlet pipe (field fabricated)

Electrostatic Precipitator
Research - Cottrell Tar precipitator, 6" Ø by 6'0" long collecting pipe type, 2 1/2 KVA 220 Volt - 35000 volt - half wave rectifier.

Recycle Gas Blower
Hoffman centrifugal blower with 75 HP motor, Δ P of 5 psig and estimated capacity of 2500 SCFM

Air Blower
Spencer Turbine blower with 40 HP motor, Δ P of 80 oz. and estimated capacity of 800 CFM

External Fired Heaters

Brown Fintube Type 102 indirect fired heaters with 20 foot section of HK40 firetube, duty 600 M BTU/h at 406-635 SCFM of gas up to gas outlet temperature of 1300°F

Retorted Shale Weighbelt

Ramsey Model 10-11 "Vey-R-Weigh" conveyor Scale System for 24" wide conveyor to handle 4 TPH of shale weighing 85-90 lbs per cu. ft. at a speed of 8.5 fpm (15.7 lbs per foot)

Semi-Works Retort System

Raw Shale Weighbelt

Ramsey Model 10-11 "Vey-R-Weigh" Conveyor Shale System for 24" wide conveyor to handle 43 TPH of shale weighing 85-90 lbs per cu. ft. at a speed of 89 fpm (15.7 per foot)

Retort

Vertical cylindrical vessel 10'-6" O.D., 8'-6" I.D. approximately 49' high with 1/4" carbon steel shell design pressure 10 psig. Retort lining consists of two layers of 1/8" Kaiser Fiberfrax insulating felt, 2 3/4" of Kaiser Celocast -20 insulating castable and two vertical courses of 4 1/2" Kaiser Jaybee SM fire clay brick. One top and two bottom Salina Model MFS 1716 rotary gas seals.

Coalescer

Vertical cylindrical vessel, 5'-0" O.D. approximately 14' high with an internal pipe 32" O.D., 5 1/2 feet packed section and oil wash sprays

Electrostatic Precipitator

Koppers concentric ring type precipitator 10' Ø by 27' high, 35 KVA silicon rectifier control console

Recycle Gas Blower

Spencer Turbine Turbo Blower with 700 HP motor, 120 oz. Δ P and estimated capacity of 14,000 CFM

Air Blower

Spencer Turbine Blower with 150 HP motor, 80 oz. Δ P and estimated capacity of 3600 SCFM

Bottom Gas Cooler

Horizontal unit, gas on shell side, water on tube side, 784 Ft^2, duty approximately, 1MM BTU/h

Paraho

External Fired Heaters

Smalling Engineering and Equipment Co., indirect fired heaters with stainless steel tubes and tubesheets, duty 7 MM BTU/hr at 3,500 to 5,000 SCMF gas rate up to gas exit temperature of 1400°F

Retorted Shale Weighbelt

Ramsey Model 10-11 "Vey-R-Weigh" Conveyor Scale system for 24" wide conveyor to handle 43 TPH of shale weighing 85-90 lbs per cu. ft. at a speed of 89 fpm (15.7 lbs per foot)

Miscellaneous

Thermal Oxidizer

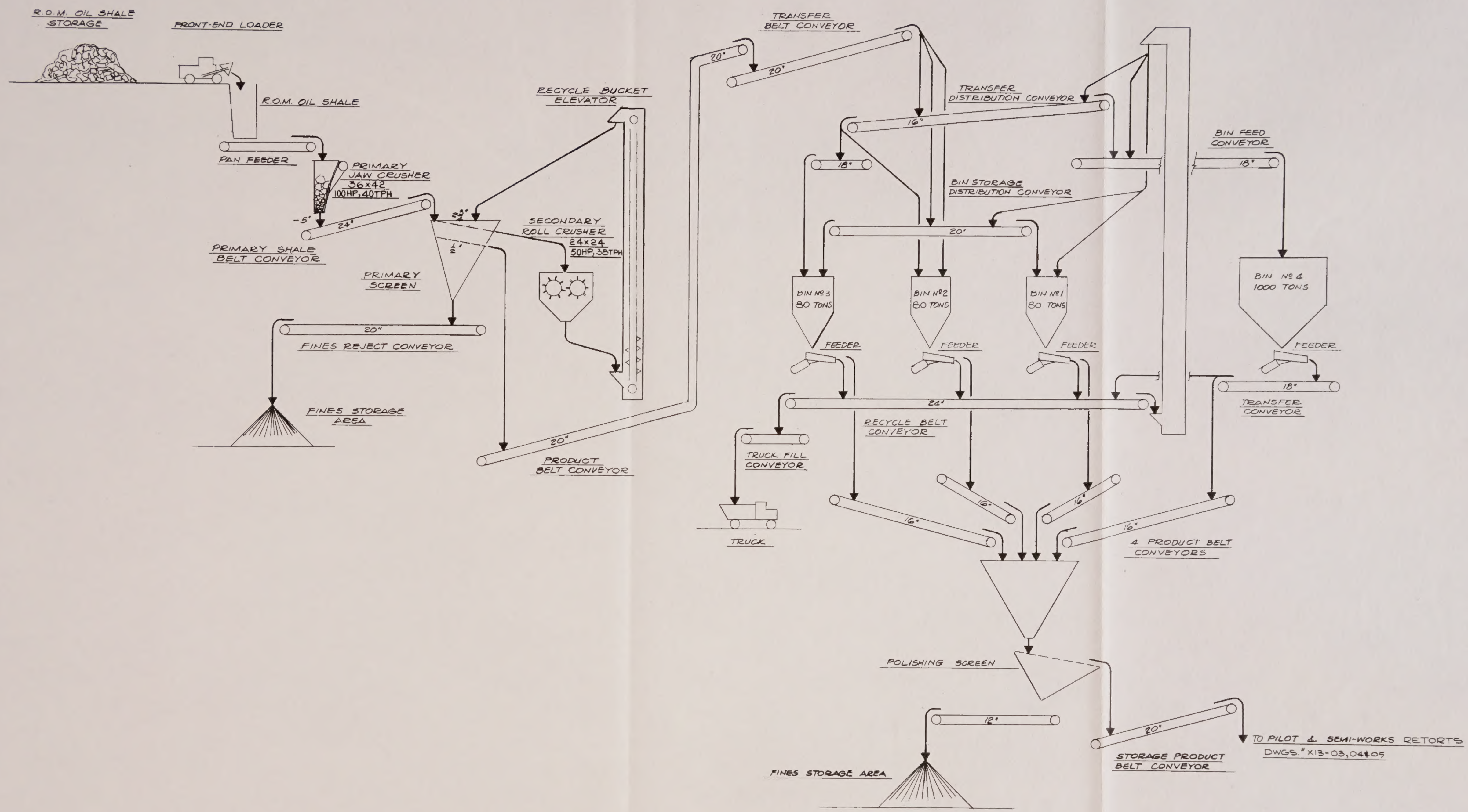
Gas Combustion Retort #3 fire box 30 feet high with 60 sq. ft. cross section area, a checker brick system in bottom and John Zink burner and controls, unit to handle 4100 SCFM of excess gas at 2000°F operating temperature of oxidizer

Steam Generators

2 Cleaver Brooks package boilers complete with boiler feed system each capable of generating 1725 #/hr of steam of 50 psig

Instrument Air

Ingersoll-Rand package air compressor complete with dryer capable of producing 125 SCFM of air at 100 psig



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CLIENT: PARAHO OIL SHALE DEMONSTRATION

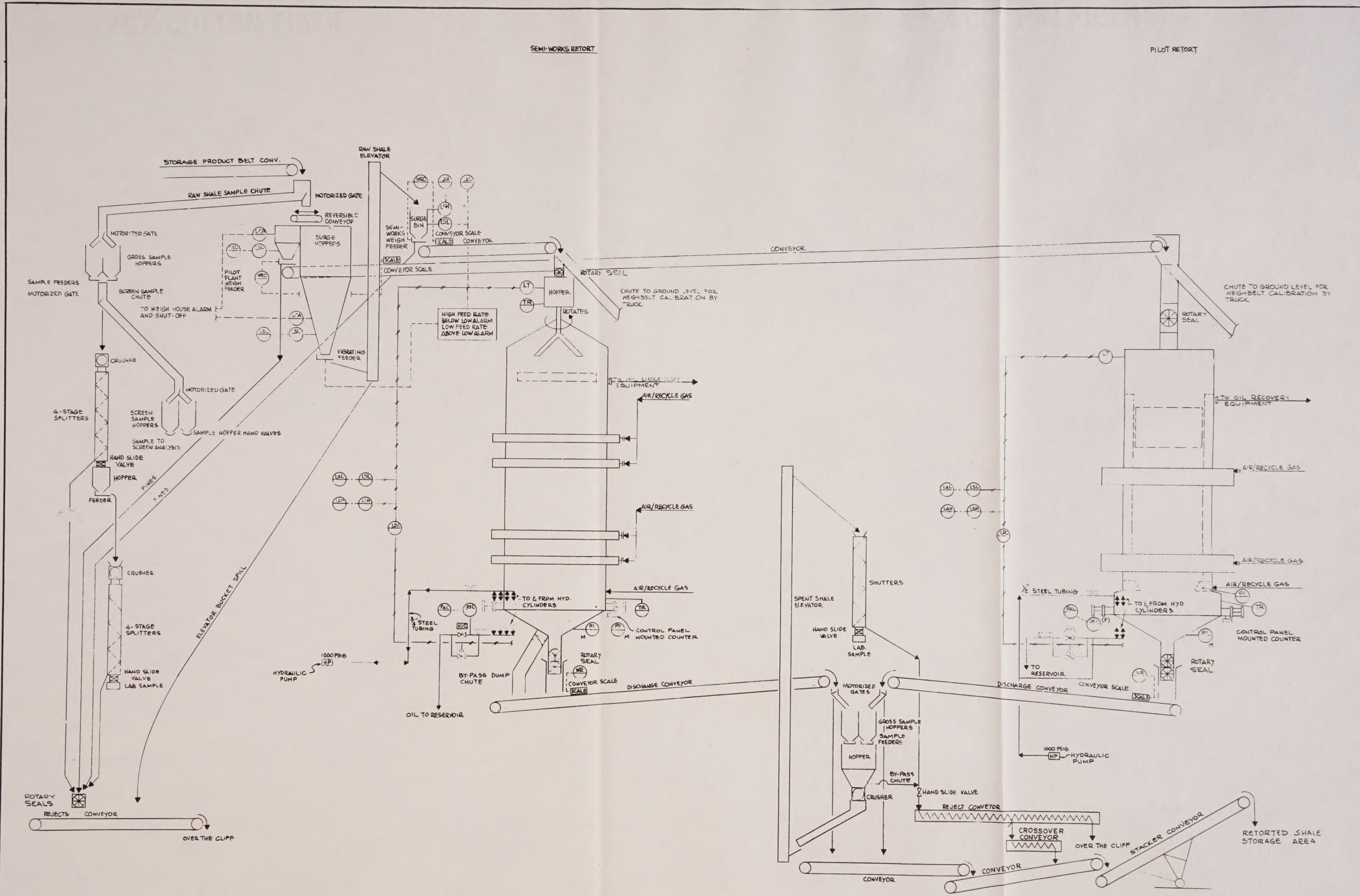
TITLE: RAW OIL SHALE FEED PREPARATION FACILITIES

SCALE ______ S.M. NO. ______

McKee ENGINEERS AND CONSTRUCTORS CLEVELAND, OHIO

DWG. 1

REVISION



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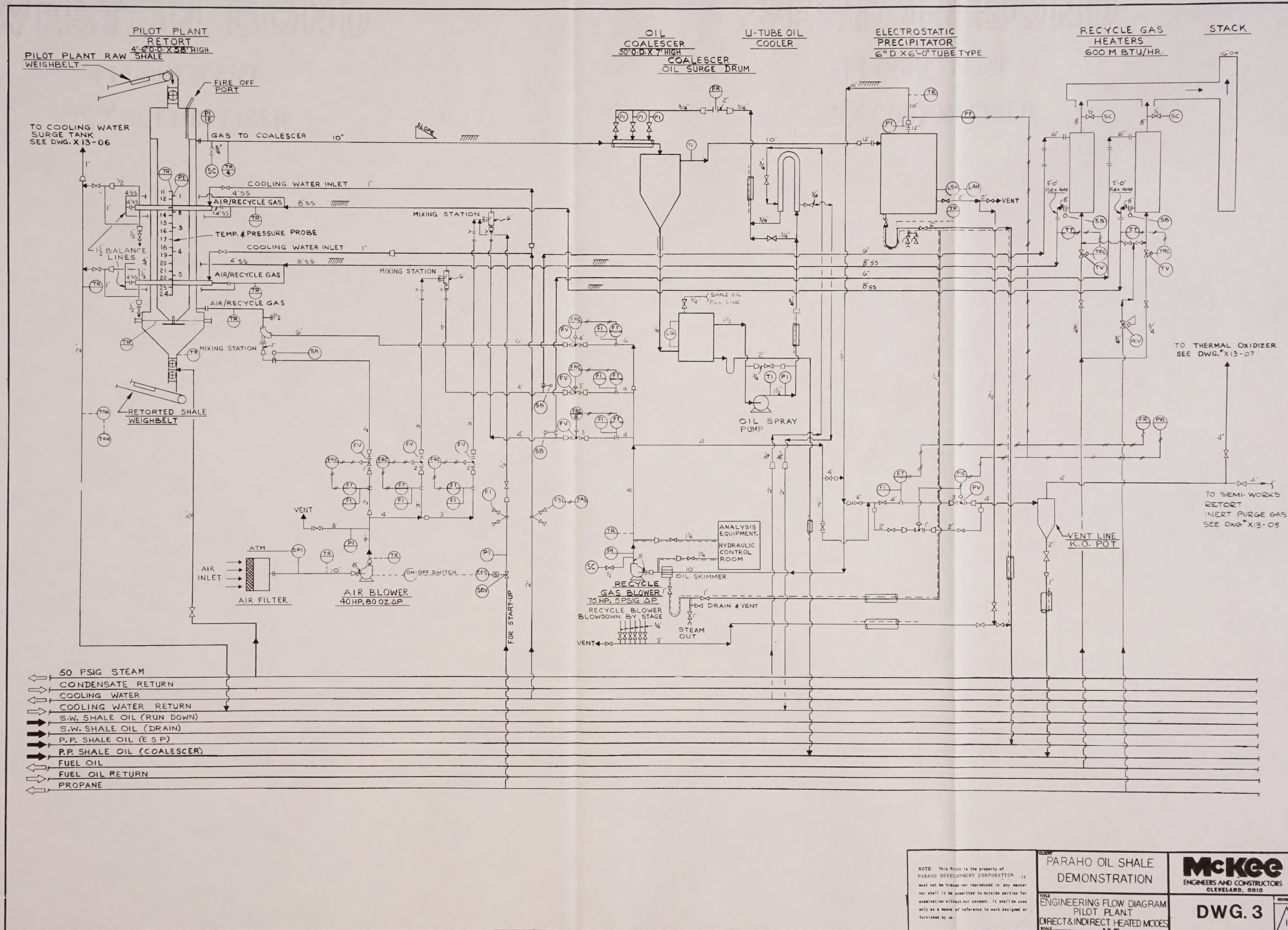
CLIENT: PARAHO OIL SHALE DEMONSTRATION

TITLE: SOLIDS HANDLING SYSTEMS PILOT & SEMI-WORKS PLANTS

McKee ENGINEERS AND CONSTRUCTORS CLEVELAND, OHIO

DWG. 2

REVISION 1



PILOT PLANT RETORT
4'-6"O.D. X 58' HIGH
PILOT PLANT RAW SHALE WEIGHBELT
FIRE OFF PORT
TO COOLING WATER SURGE TANK SEE DWG. X13-06
GAS TO COALESCER
SLOPE
COOLING WATER INLET
AIR/RECYCLE GAS
MIXING STATION
TEMP. & PRESSURE PROBE
BALANCE LINES
RETORTED SHALE WEIGHBELT
OIL COALESCER
30"O.D. X 7' HIGH
COALESCER OIL SURGE DRUM
U-TUBE OIL COOLER
ELECTROSTATIC PRECIPITATOR
6"D X 6'-0" TUBE TYPE
VENT
RECYCLE GAS HEATERS
600 M BTU/HR.
STACK
FLEX HOSE
SHALE OIL FILL LINE
OIL SPRAY PUMP
TO THERMAL OXIDIZER SEE DWG. X13-07
TO SEMI-WORKS RETORT INERT PURGE GAS SEE DWG. X13-05
VENT LINE K.O. POT
ANALYSIS EQUIPMENT.
HYDRAULIC CONTROL ROOM
OIL SKIMMER
RECYCLE GAS BLOWER
75 HP, 5 PSIG ΔP
RECYCLE BLOWER BLOWDOWN BY STAGE
DRAIN & VENT
STEAM OUT
AIR INLET
ATM
AIR FILTER
AIR BLOWER
40 HP, 80 OZ. ΔP
ON-OFF SWITCH
FOR START-UP
50 PSIG STEAM
CONDENSATE RETURN
COOLING WATER
COOLING WATER RETURN
S.W. SHALE OIL (RUN DOWN)
S.W. SHALE OIL (DRAIN)
P.P. SHALE OIL (E S P)
P.P. SHALE OIL (COALESCER)
FUEL OIL
FUEL OIL RETURN
PROPANE
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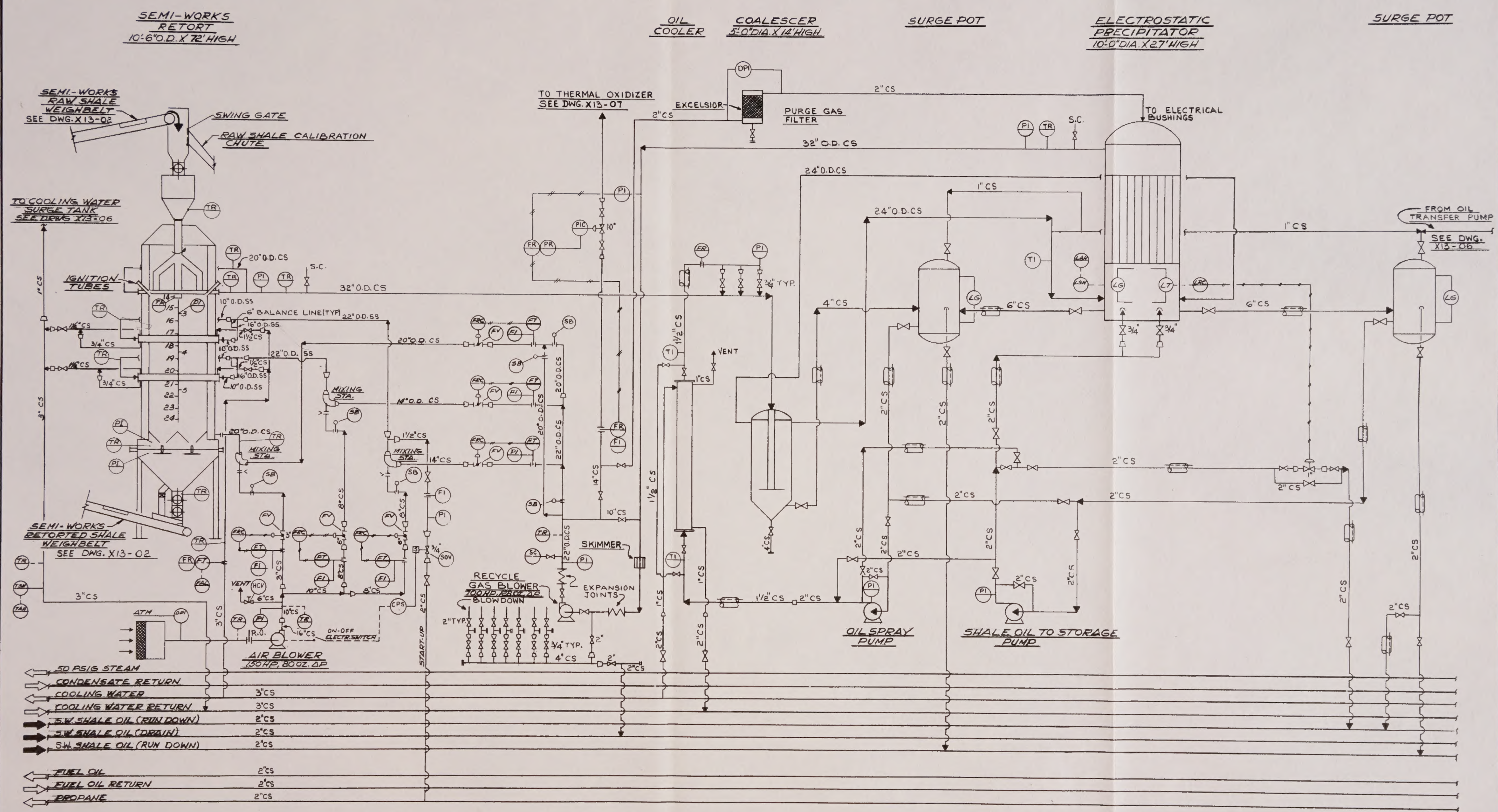
CLIENT PARAHO OIL SHALE DEMONSTRATION
TITLE ENGINEERING FLOW DIAGRAM PILOT PLANT DIRECT & INDIRECT HEATED MODES
McKEE ENGINEERS AND CONSTRUCTORS CLEVELAND, OHIO
DWG. 3
REVISION 1



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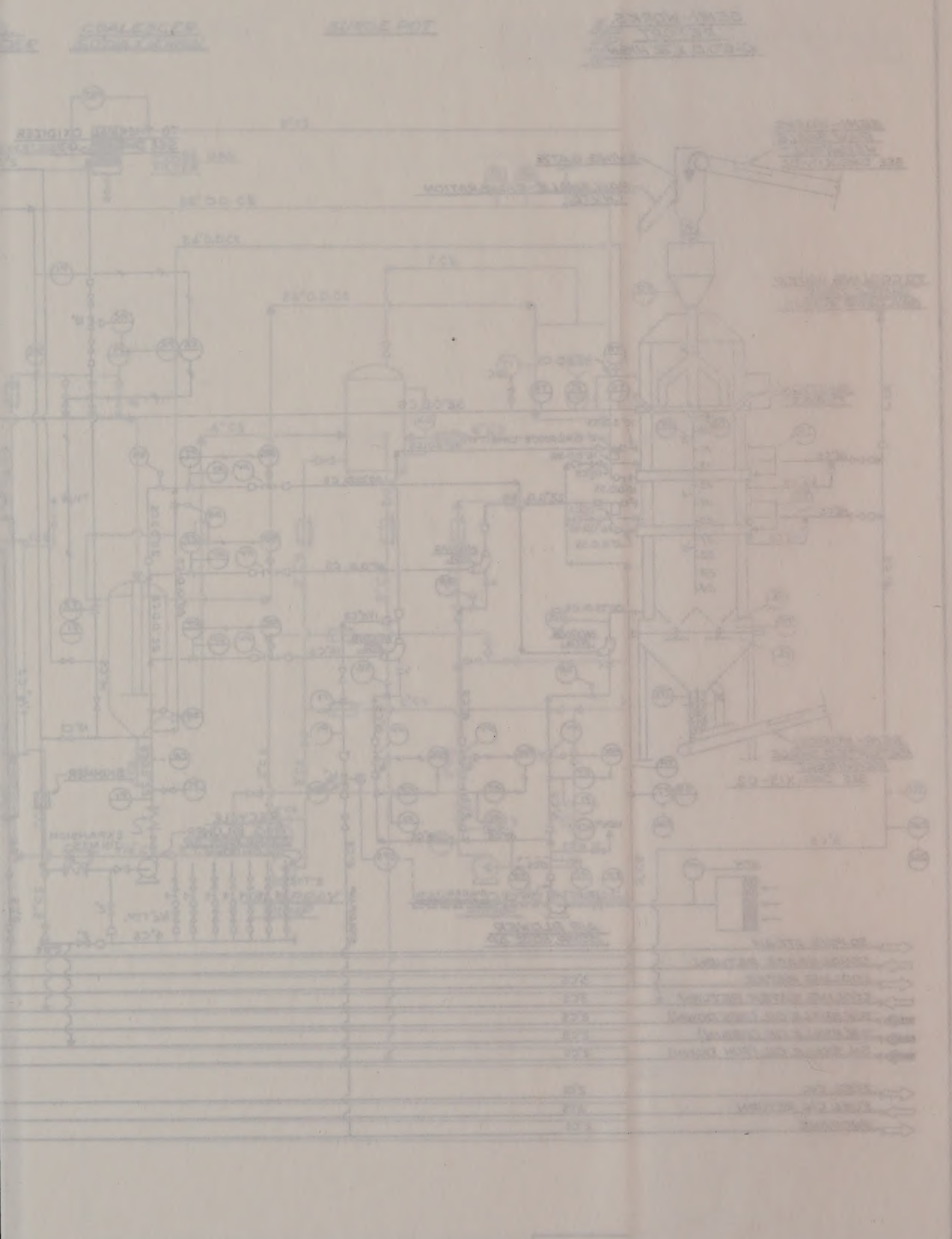
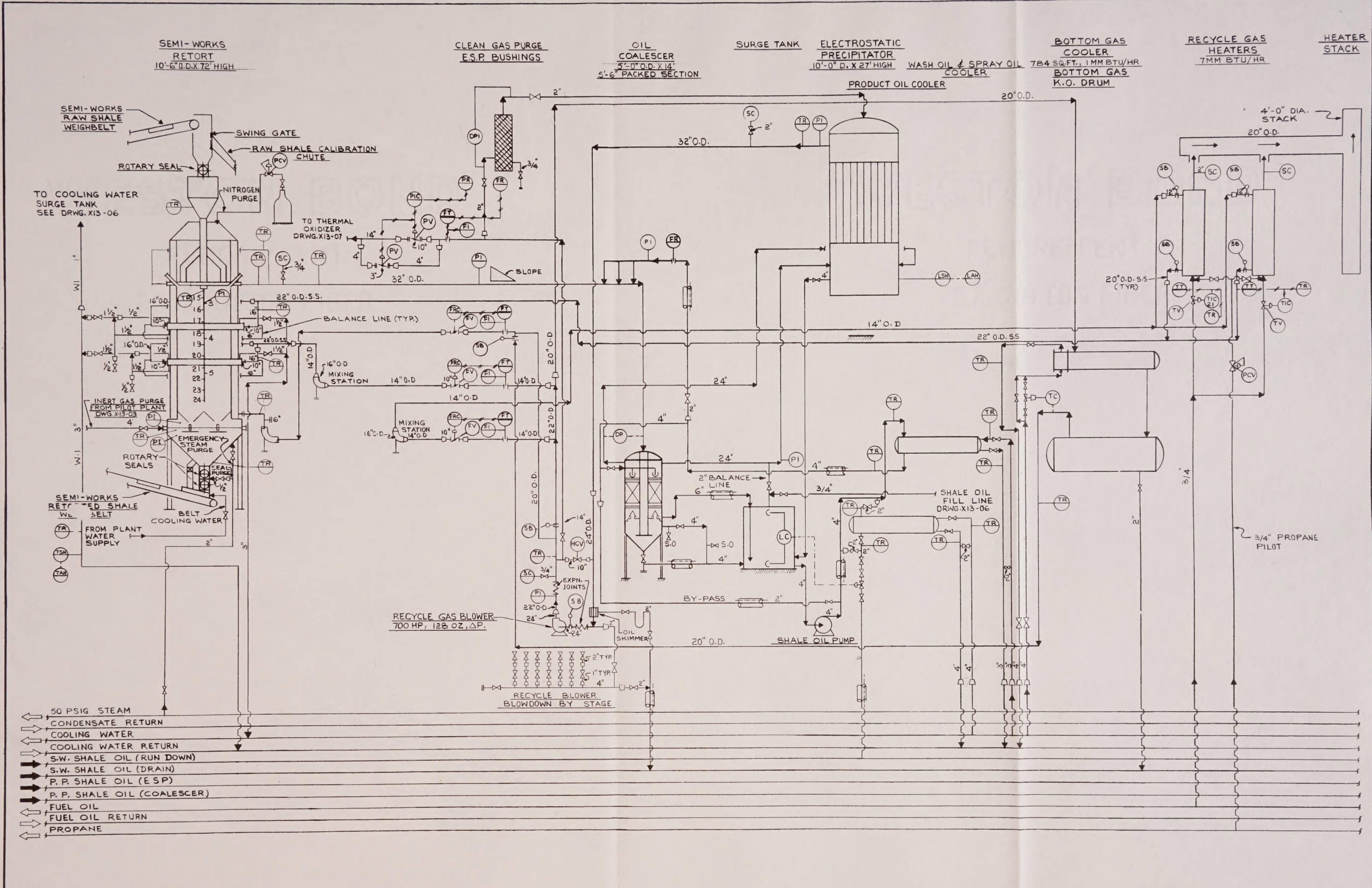
CLIENT: PARAHO OIL SHALE DEMONSTRATION	McKEE ENGINEERS AND CONSTRUCTORS CLEVELAND, OHIO
TITLE: ENGINEERING FLOW DIAGRAM SEMI-WORKS PLANT (DIRECT HEATED MODE)	DWG. 4
SCALE / B.M. NO.	REVISION 1



COALESCER
SURGE POT



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CLIENT
PARAHO OIL SHALE DEMONSTRATION

TITLE
ENGINEERING FLOW DIAGRAM
SEMI-WORKS PLANT
(INDIRECT HEATED MODE)

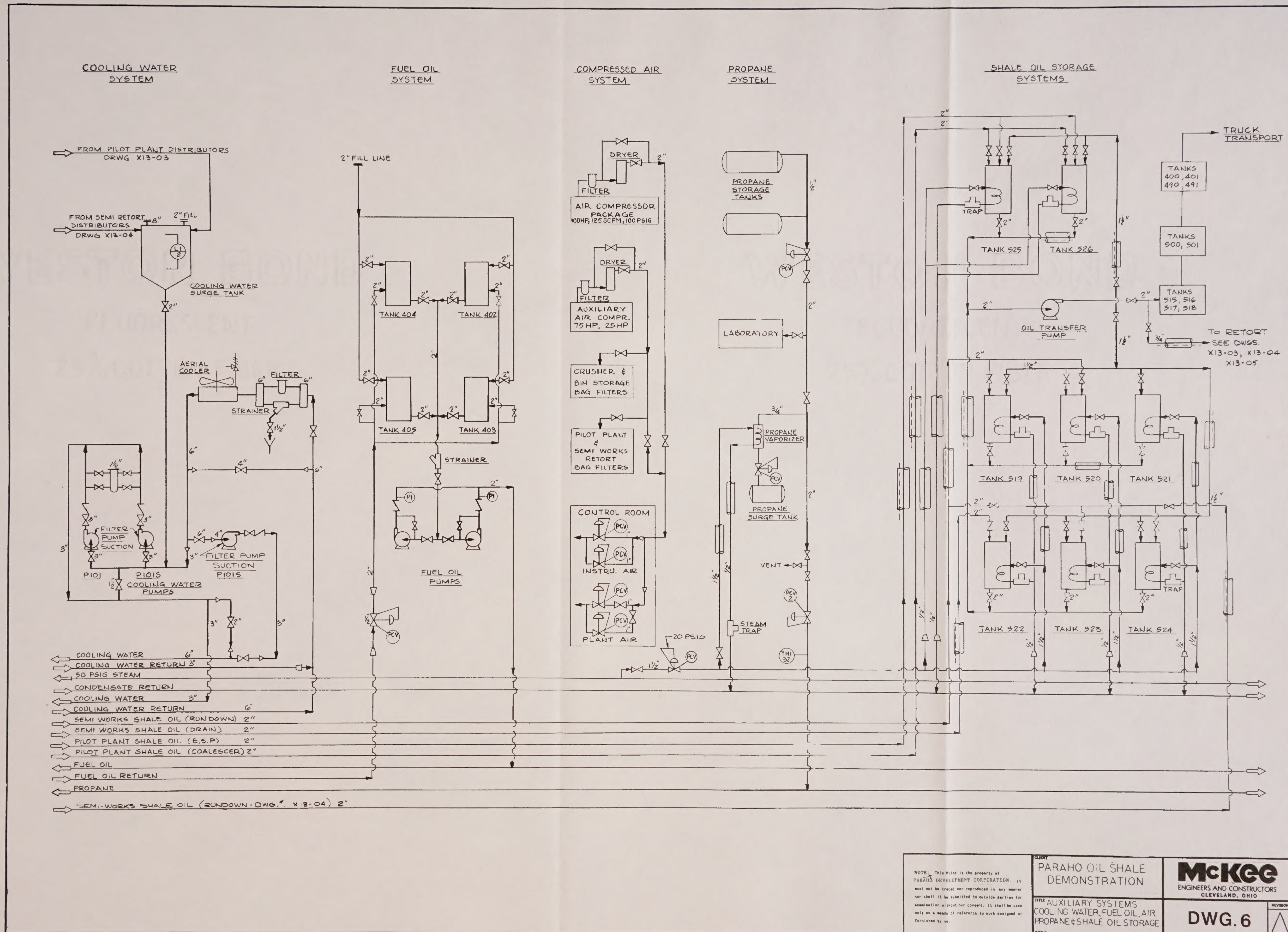
SCALE ______ R. M. NO. ______

McKee
ENGINEERS AND CONSTRUCTORS
CLEVELAND, OHIO

DWG. 5

REVISION 1


ESP BUSHINGS
SWING GATE
RAW SHALE CALIBRATION CHUTE
NITROGEN PURGE
RECYCLE GAS BLOWER


COOLING WATER SYSTEM
FUEL OIL SYSTEM
COMPRESSED AIR SYSTEM
PROPANE SYSTEM
SHALE OIL STORAGE SYSTEMS
FROM PILOT PLANT DISTRIBUTORS DRWG X13-03
FROM SEMI RETORT DISTRIBUTORS DRWG X13-04
COOLING WATER SURGE TANK
AERIAL COOLER
FILTER
STRAINER
FILTER PUMP SUCTION
P101
P101S
COOLING WATER PUMPS
FILTER PUMP SUCTION P101S
2" FILL LINE
TANK 404
TANK 402
TANK 405
TANK 403
STRAINER
FUEL OIL PUMPS
DRYER
FILTER
AIR COMPRESSOR PACKAGE 100HP, 125 SCFM, 100 PSIG
AUXILIARY AIR COMPR. 75 HP, 25 HP
CRUSHER & BIN STORAGE BAG FILTERS
PILOT PLANT & SEMI WORKS RETORT BAG FILTERS
CONTROL ROOM
INSTRU. AIR
PLANT AIR
20 PSIG
PROPANE STORAGE TANKS
LABORATORY
PROPANE VAPORIZER
PROPANE SURGE TANK
VENT
STEAM TRAP
TRAP
TANK 525
TANK 526
TANKS 400, 401 490, 491
TANKS 500, 501
TANKS 515, 516 517, 518
TRUCK TRANSPORT
OIL TRANSFER PUMP
To RETORT SEE DWGS. X13-03, X13-04 X13-05
TANK 519
TANK 520
TANK 521
TANK 522
TANK 523
TANK 524
COOLING WATER 6"
COOLING WATER RETURN 3"
50 PSIG STEAM
CONDENSATE RETURN
COOLING WATER 3"
COOLING WATER RETURN 6"
SEMI WORKS SHALE OIL (RUNDOWN) 2"
SEMI WORKS SHALE OIL (DRAIN) 2"
PILOT PLANT SHALE OIL (E.S.P) 2"
PILOT PLANT SHALE OIL (COALESCER) 2"
FUEL OIL
FUEL OIL RETURN
PROPANE
SEMI-WORKS SHALE OIL (RUNDOWN-DWG. X13-04) 2"
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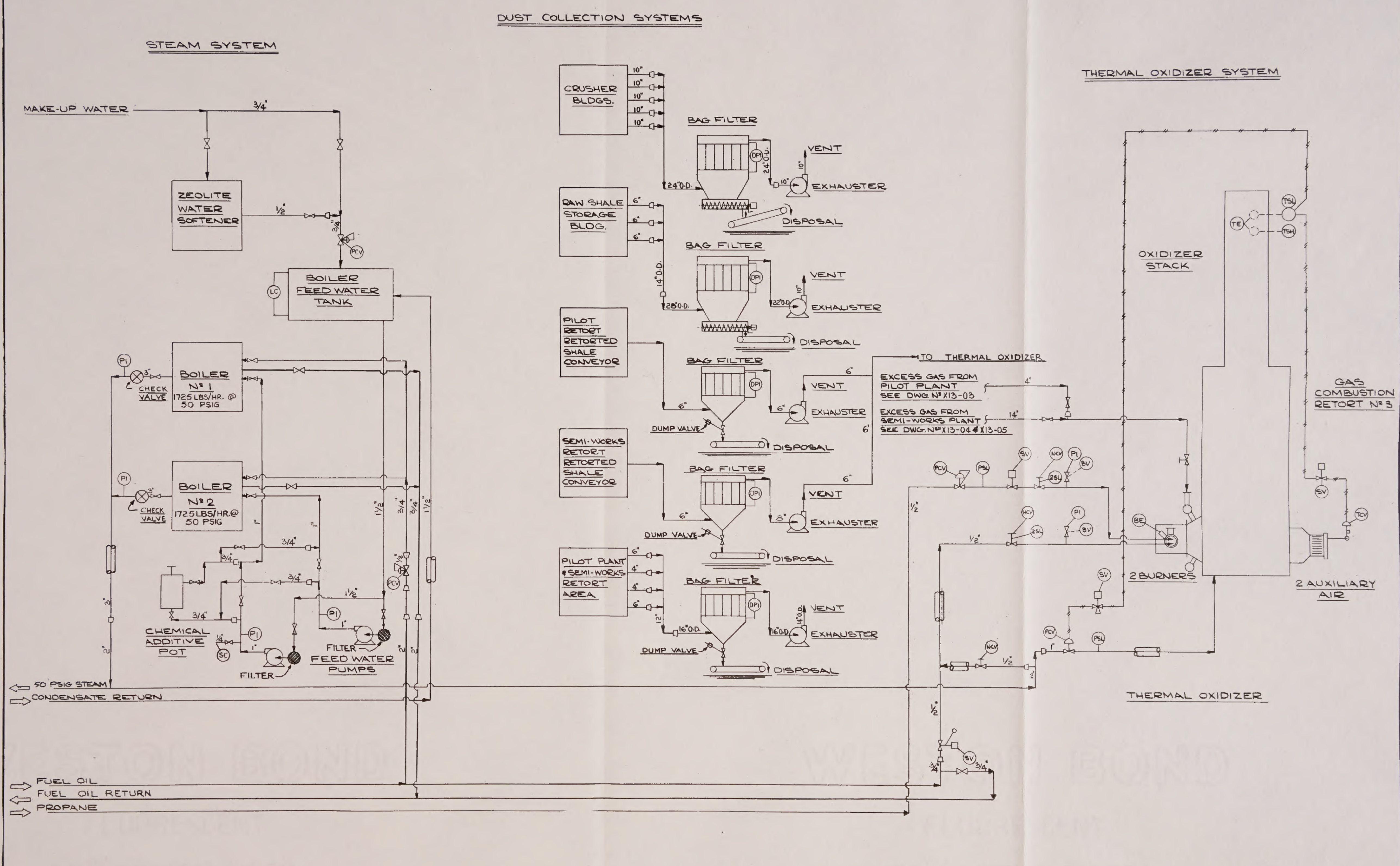
CLIENT PARAHO OIL SHALE DEMONSTRATION
TITLE AUXILIARY SYSTEMS COOLING WATER, FUEL OIL, AIR PROPANE & SHALE OIL STORAGE
McKee ENGINEERS AND CONSTRUCTORS CLEVELAND, OHIO
DWG. 6



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CLIENT: PARAHO OIL SHALE DEMONSTRATION

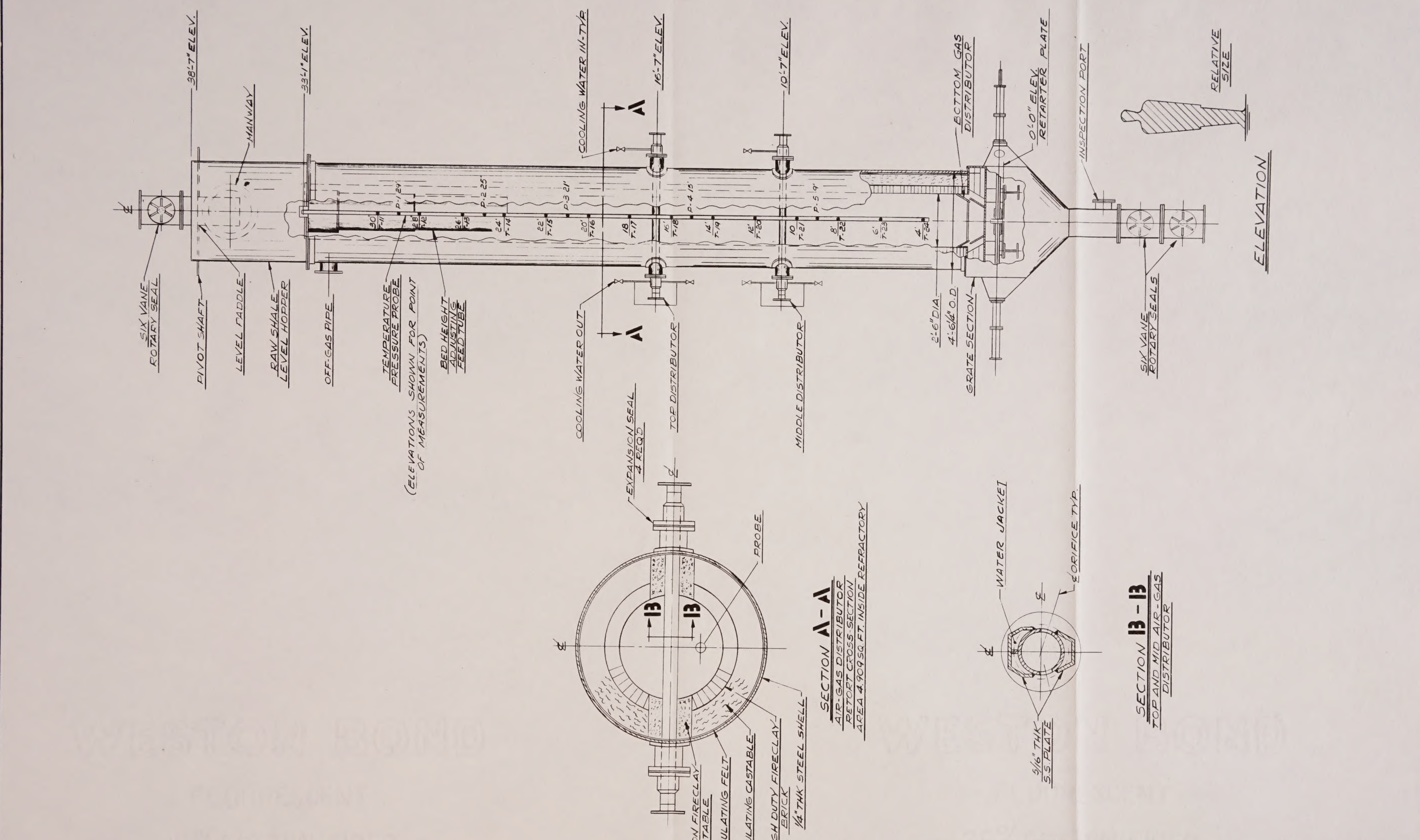
TITLE: AUXILIARY SYSTEMS STEAM, DUST COLLECTION & THERMAL OXIDIZER

SCALE ______ R.M. NO. ______

McKee ENGINEERS AND CONSTRUCTORS CLEVELAND, OHIO

DWG. 7

REVISION



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CLIENT
PARAHO OIL SHALE DEMONSTRATION

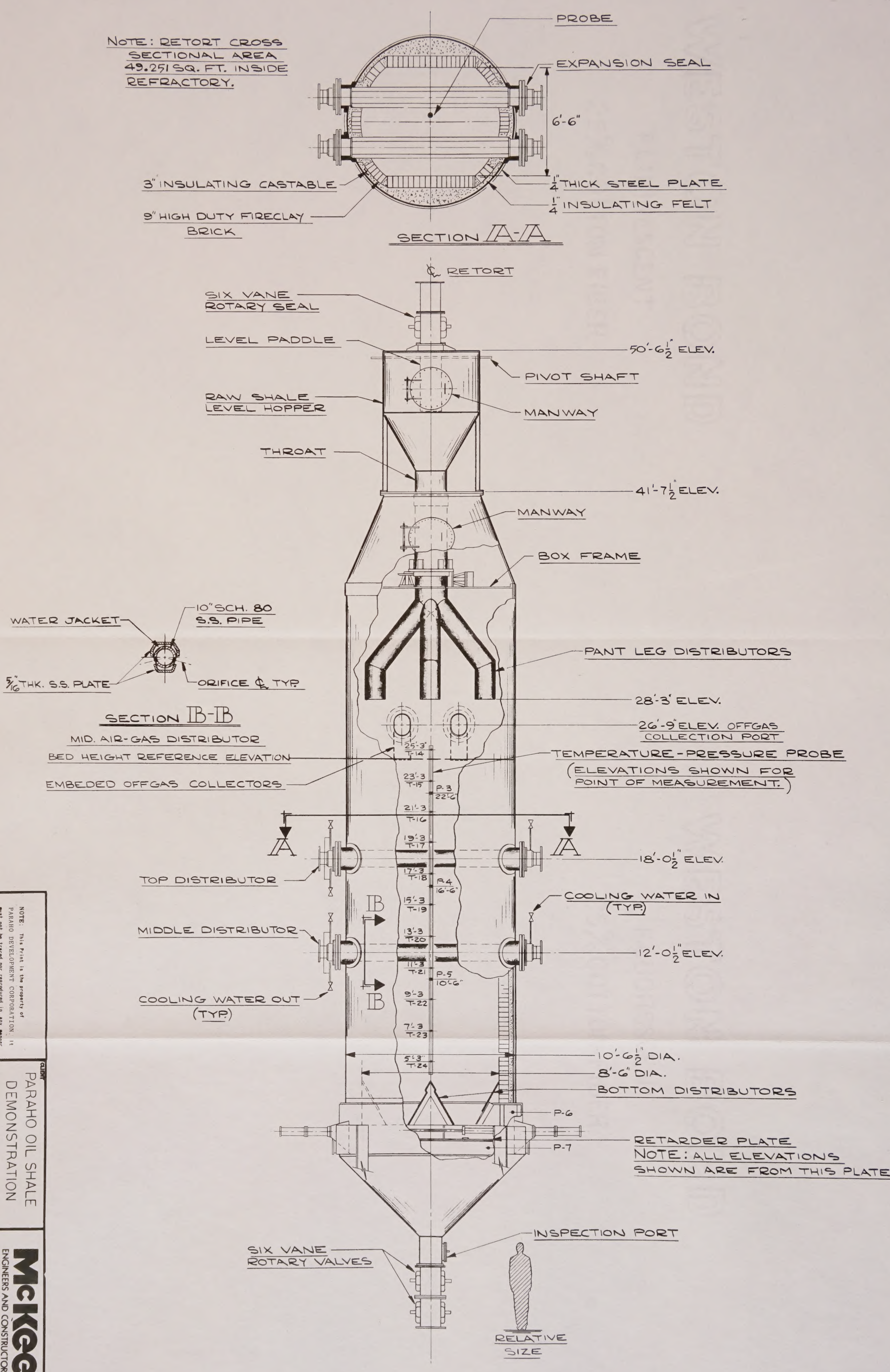
TITLE
PILOT PLANT RETORT ASSEMBLY

SCALE ______ B. M. NO. ______

McKee
ENGINEERS AND CONSTRUCTORS
CLEVELAND, OHIO

DWG. 8

REVISION



CLIENT
PARAHO OIL SHALE DEMONSTRATION

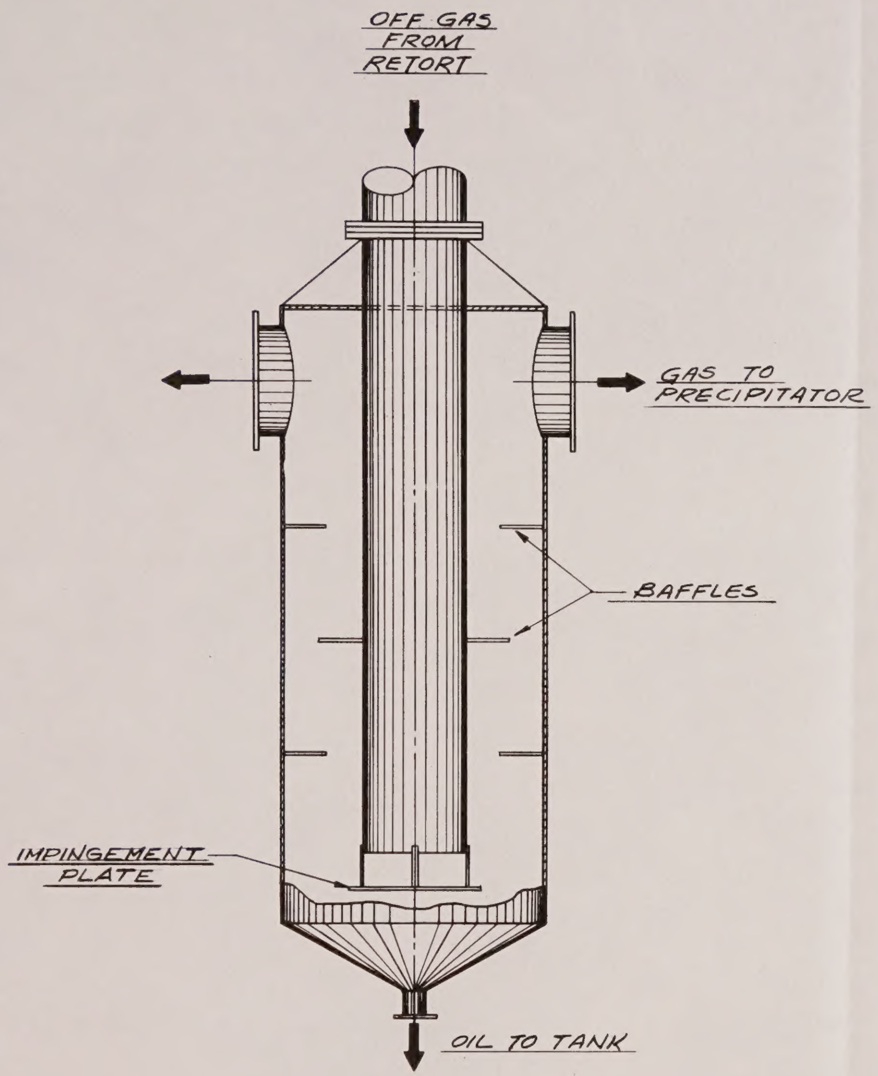
TITLE
SEMI-WORKS RETORT ASSEMBLY

SCALE
B.M. NO.

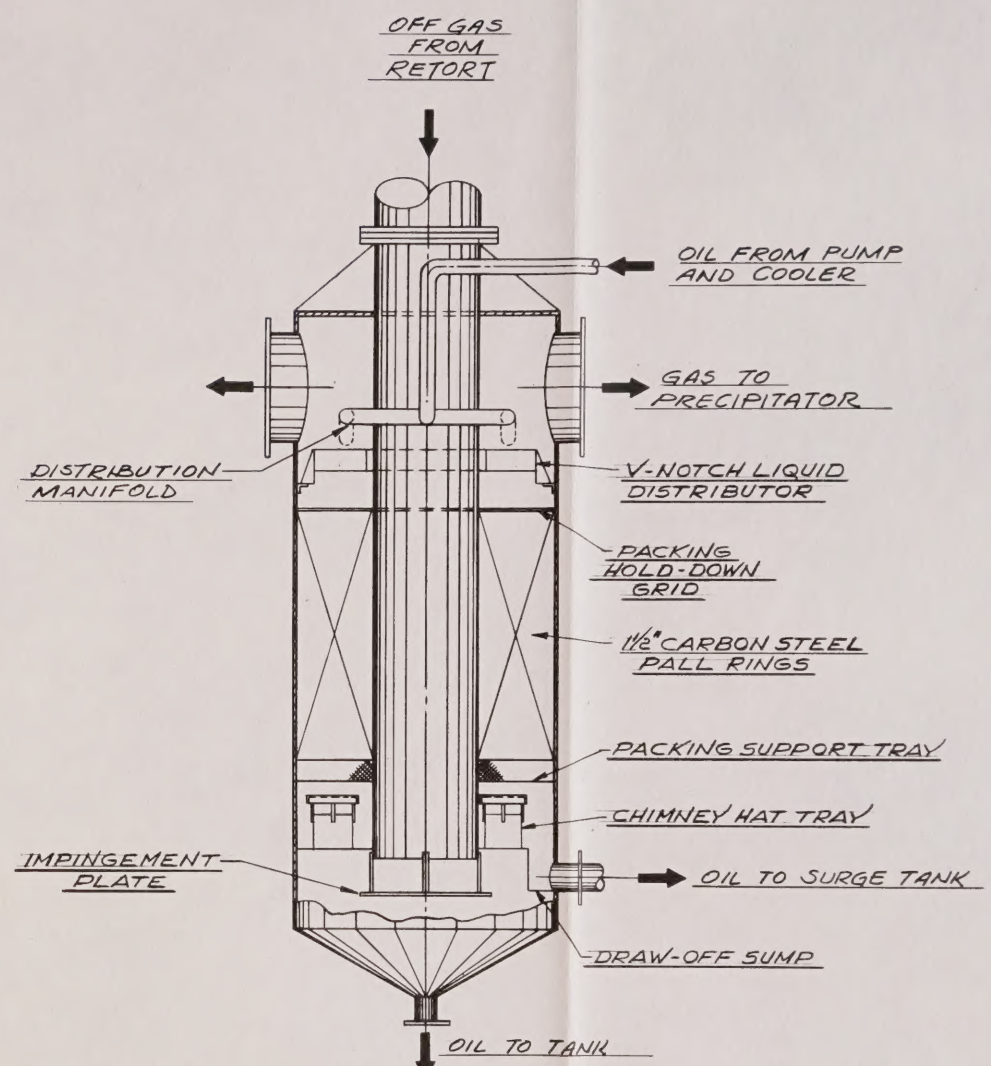
McKee
ENGINEERS AND CONSTRUCTORS
CLEVELAND, OHIO

DWG. 9

REVISION

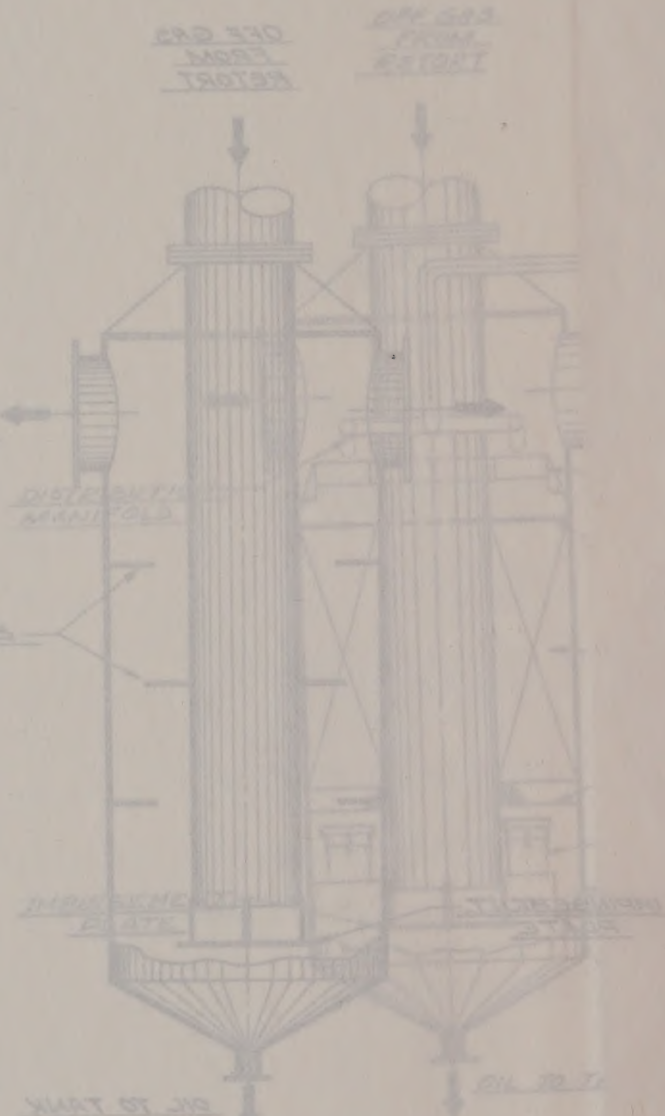


COALESCER
DIRECT HEATED PROCESS

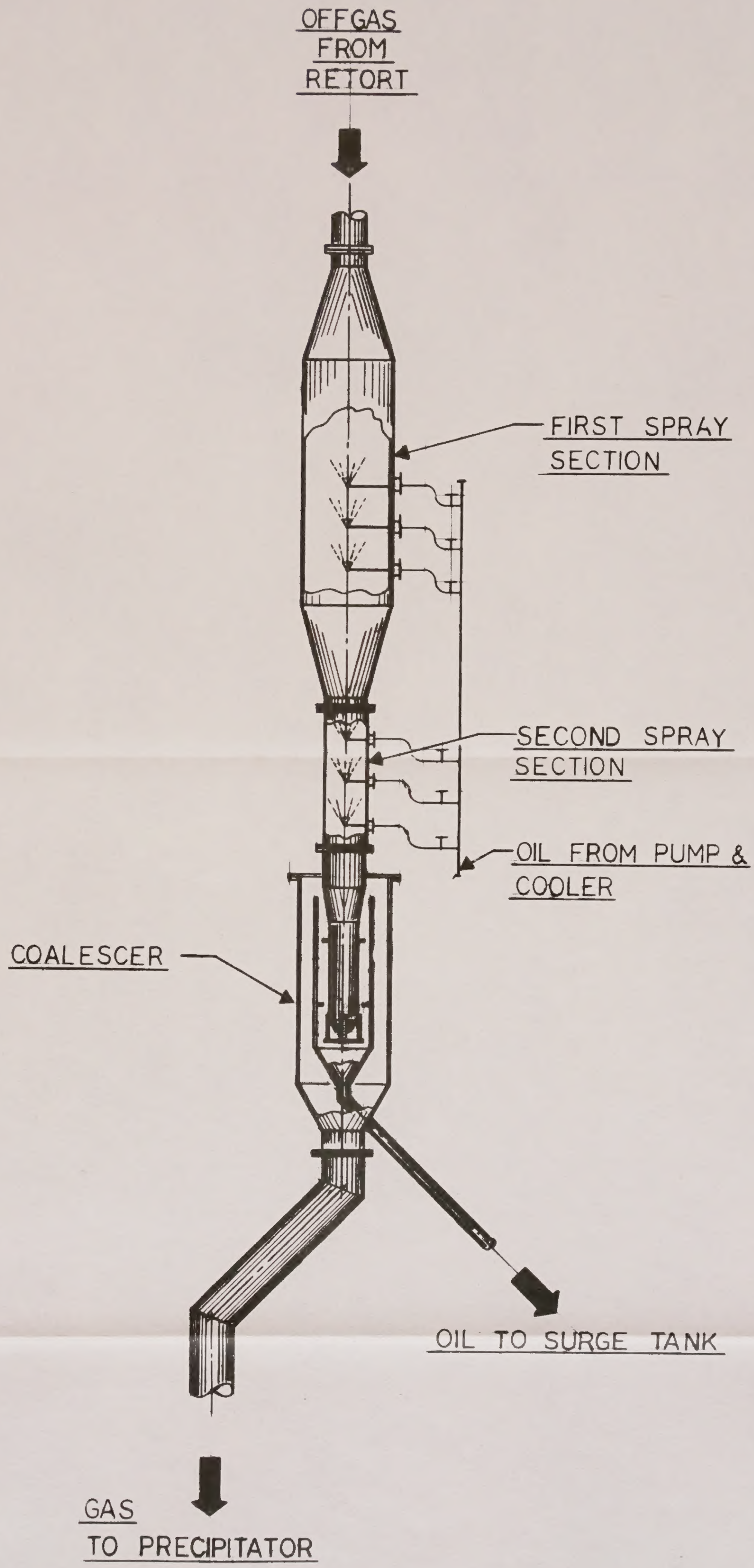


COALESCER
INDIRECT HEATED PROCESS

CLIENT PARAHO OIL SHALE DEMONSTRATION	McKee ENGINEERS AND CONSTRUCTORS CLEVELAND, OHIO	
TITLE SEMI-WORKS RETORT DIRECT & INDIRECT PROCESS COALESCERS SCALE ____ B. M. NO. ____	DWG.10	REVISION △



COALESCER
DIRECT HEATED PRO



CLIENT
PARAHO OIL SHALE DEMONSTRATION

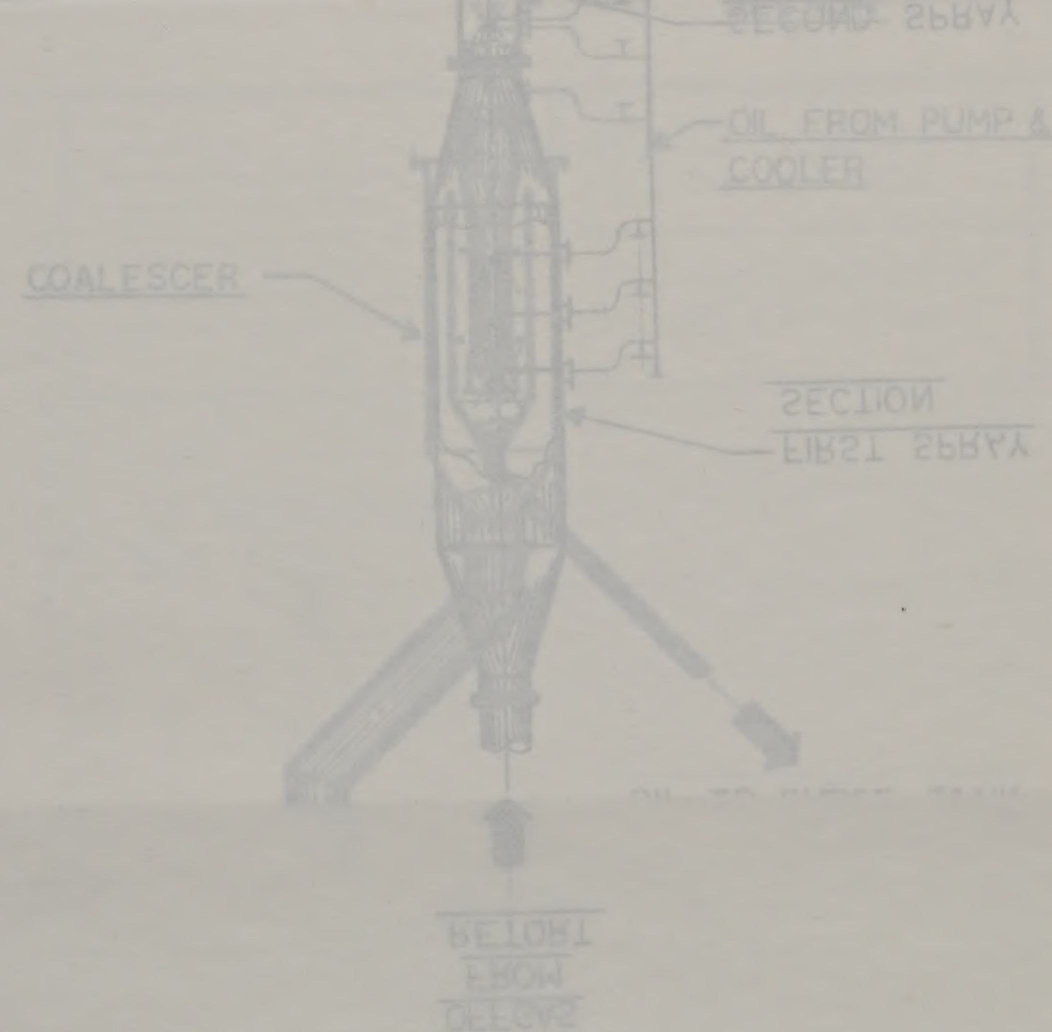
TITLE
PILOT PLANT COALESCER ASSEMBLY

SCALE ________ B. M. NO. ________

McKee
ENGINEERS AND CONSTRUCTORS
CLEVELAND, OHIO

DWG.11

REVISION


COALESCER
OIL FROM PUMP &
COOLER

APPENDIX G

GLOSSARY

Bed height -	The vertical thickness of the shale bed in the retort measured between the grate retarder plate and the bottom of the off gas collector.
Bottom gas (air) -	Gas (air) quantity to the bottom distributor located in the grate structure at the bottom of the retort.
BTU -	British thermal unit heating value. The heat needed to raise the temperature of one pound of water one degree Fahrenheit.
Carbon residue (residual carbon) -	The carbonaceous solid organic residue from pyrolysis of oil shale intimately dispersed in the retorted shale particles.
Clinkers -	Fused inorganic matter of oil shale owing to excessive temperature level.
Coalescer -	Part of the oil recovery system wherein an oil spray contacts the retort off-gas and a portion of the contained oil mist is agglomerated to a liquid oil stream.
Commercial Evaluation -	An investment and operating cost study of a commercial oil shale processing facility including mining, shale preparation, retorting, pre-refining shale oil (up-grading) retorted shale disposal, and supporting facilities.
Conveyor scales -	A device on a belt conveyor which senses continuously the weight of material being carried by the belt. The instrumentation converts the weight sensor signal and a belt speed signal to a weight rate and accumulative counter.
Dilution Gas -	Clean retort gas which is mixed with air to moderate the combustion zone temperature.
Direct Heated Mode -	Oil shale processing where heat is released inside the retort by combustion of fuel with injected air.
Distributor (Top) -	(Gas) and/or (Air) The quantity of gas and/or air entering the top distribution level in the retort.

Paraho

Distributor (Mid) -	(gas) and/or (Air) The quantity of gas and/or air entering the middle distribution level in the retort
Distributor (Btm) -	(Gas and/or (Air) The quantity of gas and/or air entering the bottom distribution level at the grate.
Dolomite -	A predominate mineral of oil shale containing equal quantities of calcium and magnesium carbonate.
ESP (Electrostatic-Precipitator)	Part of the oil recovery system wherein oil droplets are subjected to a high voltage electrostatic field. The oil droplets are impelled by the field to contact a surface to form a film of oil which drains continuously.
Fischer Assay -	A laboratory method for determining the potential oil yield from a sample of oil shale. Described in detail in Volume 4.
Full Size Module -	A large oil shale processing plant which would be one section (or module) of a commercial oil shale processing plant.
Gas Chromatograph- (GC)	Equipment for determining the composition of a gas mixture.
Grate -	A device in the bottom of a retort for controlling the descent of shale through the retort.
Gross Heating Value -	Equal to the higher heating value. The heat of combustion determined in a calorimeter and is based on the recovery of water (from combustion) as a liquid.
Heat Inventory -	Total sensible heat of the retort equipment and its contents.
Indirect Heated Mode -	Oil shale processing using hot gas heated in an external heater to supply the process heat requirements.
Kerogen -	A solid organic material containing all of the energy values in oil shale.
Marlstone -	A geological classification for oil shale. A sedimentary rock containing mixtures of Dolomite limestones and argillaceous materials.

Mass Rate - Shale processing rate usually expressed as pounds of raw shale per hour per square foot of retort cross-sectional area.

Mid Gas (Air) - Gas (air) quantity to the middle distributor.

Mine Run Shale - Oil shale blasted from the oil shale formation in the mine. The largest lumps are usually less than 30 inches in the longest dimension.

Off-gas - Retort gas containing oil mist as it leaves the retort bed through the off-gas collectors.

Off-gas Collectors - A gas removal device for the top of the shale bed. In the Semi-Works retort, it consists of two inverted transverse channels within the shale bed. The gas emerging from the channels flows to an external manifold.

Oil mist - A dispersoid of liquid oil droplets in an entraining gas stream.

Orifice Meter - A device for measuring fluid flow rate from the measured loss of pressure when the fluid flows through a restricting orifice of smaller diameter than the pipe. Specifications set by the National Gas Association.

Orsat Apparatus - Gas analysis apparatus for determination of CO_2, CO and O_2 in a gas stream.

Pilot Plant - Oil shale processing system of a vertical kiln (retort) with associated solids, gas, and liquid oil handling equipment described in detail in Section 5.1. It was used principally for retorting process studies and operation planning for the Semi-Works Plant.

Pour Point - The congealing temperature of oil as tested by prescribed ASTM procedure.

Pyrolysis - The thermal decomposition of kerogen starting at approximately 500°F and rapidly reaching complete decomposition at 900°F.

Refluxing - Condensation of oil vapors on shale descending towards the retorting zone.

Retort - A kiln or vessel for heating oil shale to temperatures to form oil and gas products.

Retorted Shale -	The residue from the retorting of oil shale composed of inorganic minerals and residual carbon from pyrolysis of kerogen.
Run -	An operation or series of operations having the same objective or purpose.
SCF -	Standard cubic feet of gas. The measured volume is converted to the volume at 60 degrees Fahrenheit and 14.7 pounds per square inch absolute pressure.
Seal (rotary) -	A device for passing solid particulate matter and simultaneously preventing the passage of gas into or out of the retort.
Semi-Works Plant -	Oil shale processing system of a vertical kiln (retort) with associated solids, gas and liquids oil handling equipment described in detail in Section 5.2. It is structurally and functionally equivalent to a commercial oil shale processing plant.
Shale size range -	The size range of shale particles, as used in the test data. This is measured by minimum square opening of the top and bottom deck screens in the crushing plant during the preparation of the raw shale in question.
Standard deviation -	A statistical measure of the spread or variability of data. In normally distributed data of an adequate population, two thirds of the data will be included in band plus and minus one standard deviation about the mean.
Standby Period -	A period in retort operations (from minutes to several hours duration) where flows of shale and processing gas and air are stopped. Retained heat in the shale bed permits a resumption of operations by restarting process flows.
Startup -	A planned stepwise procedure for the transition from a cold static bed of shale in the retort to a continuous stable retorting operation.
Temperature Proifle -	The vertical temperature gradient through the retort bed as measured by the temperature-pressure probe assembly.

Test Period	-	A continuous period of time of stable operations during a retort run where operating data and laboratory results are obtained and summarized.
Thermal Oxidizer	-	A gas incinerator for the disposal of gas with excess air and supplemental fuel if required.
Top Gas (air)	-	Gas (air) quantity to the top distributor.
Vertical Kiln	-	A vertical vessel for continuous counter-current processing of granular solids with gas.
Void Space	-	In a bulk of crushed and screened solid material, the volume of air space is called the void space. It is about 40% of the entire volume.
Weighbelt	-	Conveyor scales.

APPENDIX H

LIST OF ABBREVIATIONS

^{o}API	-	(degrees API) Specific Gravity of oil measured on the scale defined by the American Petroleum Institute
Ar	-	Argon
BS	-	Bottom sediment
Btm	-	Bottom
BTU	-	British Thermal Unit
C5+	-	Liquid hydrocarbon mixtures with components having 5 or more carbon atoms
dist	-	(distri) distributor
Dmmd	-	mean particle size of mist (in microns) See Laboratory Report, Volume 4
^{o}F	-	degrees Fahrenheit
F.A.	-	Fischer Assay
GPM	-	Gallons (U.S.) per minute
GPT	-	Gallons Per Ton
lbs/hr/ft^2	-	Pounds of raw shale per square foot of the vessel inside diameter per hour
lbs/MSCF	-	Pounds per thousand standard cubic foot
mid	-	middle
O.D.	-	Outside diameter
PP	-	Pilot Plant
raw shale	-	Mined oil shale which has been crushed and screened. Retort feed is a synonym
RS	-	Raw shale
SCF/T	-	Standard cubic feet per ton of raw shale
SUS	-	Saybolt Universal Seconds. A test for viscosity.
SW	-	Semi-Works
Ton (T)	-	short ton 2000 pounds

TPH	-	Tons per hour
wt.%	-	Weight percent